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# **HUMAN PHYSIOLOGY**

**PREPARED WITH SPECIAL REFERENCE TO  
STUDENTS OF MEDICINE**

**BY**  
**JOSEPH HOWARD RAYMOND, A.M., M.D.**  
**Professor of Physiology and Hygiene in the Long Island College Hospital, New York City**

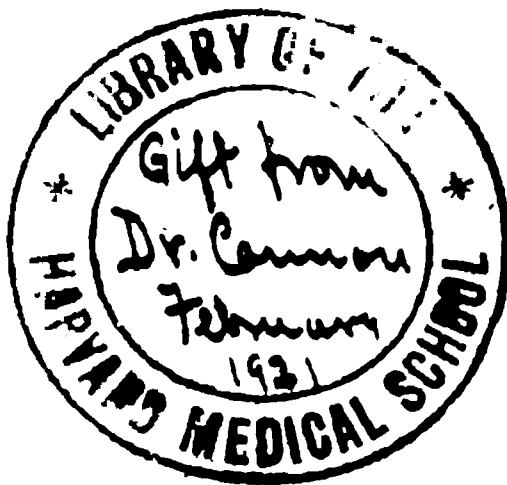
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**THIRD EDITION, THOROUGHLY REVISED**

*444 Illustrations, some of them in Colors, and 4 full-page  
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**PHILADELPHIA AND LONDON**  
**W. B. SAUNDERS & COMPANY**  
**1905**



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Set up, electrotyped, printed, and copyrighted September, 1894. Reprinted March, 1895.  
Revised, entirely reset, reprinted, and recopyrighted September, 1901.  
Revised, reprinted, and recopyrighted April, 1905.

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## PREFACE TO THE THIRD EDITION.

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IN the present edition the author has availed himself of the valuable contribution of Chittenden, under the title of "Physiological Economy of Nutrition," to this portion of Human Physiology. The results of the experiments therein reported he regards as among the most important additions to the physiology of nutrition made during the present decade.

The completion of the work of Atwater and others, as recorded in the publication entitled "Physiological Aspects of the Liquor Problem," has enabled the author to discuss more fully the nutritive value of alcohol.

Among other topics, either more fully elaborated or introduced for the first time, are: Vegetarianism; The Identity of Human and Bovine Tuberculosis in connection with the subject of Food; The Experiments of Cannon and others on the Movements of the Stomach and Intestines; The Influence of Alcohol and Alcoholic Fluids on the Excretion of Uric Acid; Hemolysis and Bacteriolysis; The Effect of Cold on Bacteria with reference to the purification of water in freezing; and Ovarian and Abdominal Pregnancy.

Many other minor changes have been made in the text, rendered necessary by the advance in Physiology since the publication of the previous edition.

The author desires to extend his thanks to critics who have pointed out defects in the former edition, which might otherwise have escaped detection, and all of which he hopes have been corrected in the present edition.

APRIL 15, 1905.



## PREFACE.

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THE author's experience of twenty years as a teacher of Physiology to medical students has brought him to the conclusion that in the short time allotted to the study of physiology in medical schools students can assimilate only the main facts and principles of this branch of medicine, which lies at the very foundation of a sound knowledge of the healing art; and that even if there were time to investigate the more recondite and abstruse parts of the subject, such an investigation would be profitless during this formative period. In his teaching the author has kept this thought constantly in mind, and in this manual has endeavored to put into a concrete and available form the results of his experience.



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# HUMAN PHYSIOLOGY.

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## INTRODUCTION.

**Definitions.**—Physiology is *the science which treats of functions*. By the term *function* is meant the characteristic work performed by an organ. An organ may be defined as a structure which performs a function or functions, for the special or characteristic work of an organ may not be limited to a single function: thus the pancreas secretes not only pancreatic juice, which is its *external secretion*, but also another product, which is its *internal secretion* (p. 239). Lifeless things perform no functions, hence physiology has no dealings with inanimate things. Rocks, stones, and other members of the mineral kingdom at no time possess life; consequently they perform no functions, and with them physiology has no concern: we cannot speak of the physiology of minerals. Plants and animals are sometimes living and sometimes dead: when living they perform functions, when dead they perform no functions; in the latter condition they are like the rocks so far as function is concerned, and with them physiology has nothing whatever to do. It is only when they are living that they perform functions, and it is then and only then that with them physiology concerns itself.

Another definition which might be given of physiology is, that it is *the science which treats of vital phenomena*. A brief consideration of this definition will bring us to the same conclusion as did that of the preceding definition. Of life in its essence we know nothing. Metaphysicians have endeavored to explain life, and some have even ventured to point out its seat, but the fact remains that we are utterly ignorant of its nature. We only know that it exists by certain manifestations which it presents. When we see a growing plant or a moving animal, we say of each that it is alive. In the higher forms of animals and plants it is easy, under ordinary circumstances, to determine whether they are living or not; but in the lower forms this determination is sometimes a most difficult task. The evidences upon which reliance is placed to determine the presence or the absence of life are spoken of as *vital phenomena*. Thus, if in examining an animal we find that its heart beats, we say that the animal is alive; but

if the heart is motionless, we say that the animal is dead. This beating of the heart, therefore, is a vital phenomenon—that is, a manifestation of life. We speak also of this beating of the heart as its function; hence the first definition of physiology, that it is the science which treats of functions, and the second definition, that it is the science which treats of vital phenomena, amount to the same thing.

**Definition of "Organ."**—An organ has already been defined as a structure which performs a function or functions. In speaking of the organs of an animal reference is usually had to such structures as the heart, the lungs, and the stomach, inasmuch as their size and the important work they perform force them upon our attention. These are indeed organs, for they perform functions; thus the function of the heart is to receive blood in one portion and to propel it from another portion, that of the lungs is to aërate the blood, and that of the stomach is to digest certain kinds of food; but the term *organ*, as used in physiology, has a much broader signification. A muscle, a nerve, and a blood-vessel are as truly organs as are the greater ones above spoken of, for each has its own function. Thus the function of a muscle is to contract, that of a nerve is to transfer nervous impulses, and that of a blood-vessel is to convey blood. At first sight it might seem that these functions were unimportant, and that the structures which performed them were hardly worthy of so dignified a name as organs; but a moment's reflection will show that without the contraction of muscles, the transference of nervous impulses, or the carrying of blood the life of an animal would as certainly cease as if it was deprived of its heart, of its lungs, or of its stomach.

Inasmuch as minerals, on the one hand, possess no organs, they perform no work—that is, they have no functions; therefore we do not speak of the physiology of a mineral. Plants and animals, on the other hand, possess organs, each of which performs its special function; and it is with them, as has been said, that physiology has to do. As we find organs in the animal, so do we find them in the plant; not the same organs, it is true, but structures which are as truly organs, for they respond to the same test. The roots of a plant absorb moisture and nourishment from the soil, this being their function; the green leaves take up from the air carbonic acid, with which and with water they form starch that is utilized by the plant, while oxygen is set free, this being the function of the leaves; the anthers and the ovaries of flowers are concerned in reproducing plants by forming new ones, this being their function. Thus we might continue to show that as in animals, so in plants, the different organs have their respective functions.

**Definition of "Organic" and "Inorganic."**—We can now understand the meaning of two very important terms—*organic* and

*inorganic*. These terms are used in two senses : first, as to *structure*, and, second, as to *product*. When we say that a plant or an animal is organic, we mean that it is made up of organs—that is, of structures which perform functions. The plant or the animal may be simple or may be complex, but, however simple or however complex, its parts do something, that something being the function of the part which acts. We say, therefore, that the plant or animal is organic, meaning that it is composed of organs—organic, then, as to structure. The rock has no organs, therefore it is *non-organic*, or is *inorganic*. These terms are used also in another sense. Thus we speak of honey as organic. Manifestly, we do not mean organic as to structure, for honey has no organs, that is, no parts which perform functions, but it is the product of the bee, which is an organic structure ; hence honey is an organic product. The nectary of a flower is organic as to structure, and the nectar which it produces is also organic, inasmuch as it is the product of the nectary.

But organs do not act each for itself: they are, as a rule, associated in the performance of a common function, and thus associated form a system. Thus the group of organs which are concerned in digestion forms the digestive system ; those which together accomplish the circulation of the blood, the circulatory system. An attempt has been made to distinguish an *apparatus* from a *system* ; the former being defined as a group of organs concerned in the performance of a common function, no matter how dissimilar their structure, while organs similar in structure irrespective of their function would be regarded as a system. Similarity of function, under this definition, would characterize an apparatus, and similarity of structure a system. The organs whose functions are to digest food would be regarded as an apparatus, constituting the digestive apparatus ; the bones, on the other hand, would form the osseous system. Practically, however, such a differentiation is of no use, and the two terms apparatus and system may therefore be used interchangeably.

**Branches of Physiology.**—From these elementary considerations it is evident that physiology has to do with living plants and animals only—that is, with organic structures and incidentally with their products. That branch of the science which treats of the functions of plants is denominated Vegetable Physiology, and that which deals with the functions of animals is called Animal Physiology.

**Vegetable Physiology.**—We are concerned but indirectly with vegetable physiology, or so far only as its study helps us to understand some of the more obscure processes in animals. Some of these processes, being simpler in plants, are more easily studied in them, and what is there learned is of great assistance in understanding analogous processes in man. Thus a knowledge of fertilization as

it occurs in the vegetable kingdom aids very much in elucidating the process of reproduction in the human species.

**Animal Physiology.**—The same organs in different animals perform their functions in different ways. Thus the stomach of the cow and that of the dog act very dissimilarly, and a knowledge of the one would aid very little in acquiring a knowledge of the other. What is true of the stomach is true of other organs to a greater or lesser degree. Each class of animals has its own peculiarities as to function—that is, has its own physiology. One who intends to devote his life to the treatment of the diseases of the lower animals must study the functions of those animals, while one who is preparing himself for the cure of human diseases must understand the functions of the organs of the human body, or **Human Physiology**.

Many hints, it is true, may be obtained by the student of human physiology from a study of the processes which take place in the lower animals, and many of the most valuable contributions made to physiologic science have been based upon such a study; but it must ever be borne in mind that specific differences exist, and that we cannot infer too much from such observations. Thus one who studies the process of stomach digestion in a ruminant, such as the cow, will make a most serious blunder should he suppose that the process is the same in man. Errors of a similar character, though perhaps less glaring, have been made, notably in the process of reproduction. This process is so obscure that many opportunities which have presented themselves for investigation, both in the lower and in the higher animals, have been seized upon; but theories which have been accepted as proved, and which have largely depended on such observations, are now, in the light of more recent study, being questioned. Notwithstanding this disadvantage, had it not been for such studies many of the most important facts of medical science would have remained undiscovered. Inasmuch as functions cease with life, these observations can only be made upon living animals. *Vivisection*, therefore, has been of the greatest benefit to the human race, and those who decry it are daily reaping the results which it has attained, and which could never have been attained without it. Wanton and unnecessary experiments are to be condemned, but no terms of praise are too exalted to bestow upon those patient investigators who, through many long years, have laboriously and zealously pursued their studies and experiments, with no other end in view than to add to the sum of human knowledge and to contribute to the relief of human suffering.

**Human Physiology Defined.**—Human physiology is *the science which treats of the human functions*. This science, together with *anatomy*, which treats of structure, and with *chemistry*, which treats of composition, lies at the foundation of rational medicine.



No one can be a successful physician who does not understand at least the more important functions of the human body, and the greater the knowledge he possesses of physiology, the broader will be the scientific groundwork on which he has to build. Disease is a departure from the normal or physiologic condition. A diseased organ performs its function in an abnormal manner, and to succeed in correcting the diseased condition one must first be able to recognize this abnormal action, which can only be done by knowing how the organ acts in health—that is, by understanding its physiology. Even with this knowledge one may be unable to accomplish the desired object, for the structure of the organ may be so changed that no means can be applied which will restore it to its normal condition; but one is certainly more likely to succeed if possessed of a knowledge of its physiology than if ignorant of it. The study of human physiology is but the study of the human functions, and when these functions are thoroughly understood the science is mastered.

**Classification of Functions.**—The functions of the body may be classified as follows: 1. *Nutritive Functions*, which include those concerned directly with the maintenance of the individual, such as digestion, respiration, circulation, etc.; 2. *Nervous Functions*, which include those that bring the different organs of the body into harmonious relations with one another, and, in addition, bring the individual, through the special senses—sight, hearing, etc.—into relation with the world outside him; and 3. *Reproductive Functions*, which are concerned not with the individual, but with the *species*, which they perpetuate.

**Histology of the Human Body.**—Anatomy, as we have already learned, is the science which treats of structure; and this is true as well of the minute or microscopic as of the gross or macroscopic structure; but it will be of advantage to the student of physiology to have distinctly in mind so much of the histology or minute structure of the body as is necessary to a full understanding of its functions, and to appreciate the discussion of them. With this end in view, the histology of each organ will be given in connection with its function, but preliminary to all this we shall discuss the tissues of the body which go to make up these organs. For fuller details the student is referred to the many excellent treatises on human histology.

**Physiologic Chemistry.**—Although physiology, strictly speaking, has nothing to do with composition, still, as a matter of necessity as well as of convenience, it is usual to preface the study of the functions of the human body with a greater or lesser consideration of its composition. This consideration is necessary, because, as a rule, medical students have an insufficient knowledge of this branch of chemistry—physiologic chemistry—to take up at once the study of the functions with profit, and should the

attempt be made confusion and loss of time would inevitably result. As an illustration we may refer to the function or series of functions by which the food is prepared for absorption—that is, digestion. Food is the material which is taken into the body to supply the waste of its tissues, and it must be of such a composition as will meet this want. To select the proper food-materials we must know of what the body is composed, and what are the changes which take place in its composition—what parts are wasted. For these reasons a study of *physiologic chemistry* must precede a study of the functions of digestion. This is but one of many illustrations which might be given to show the importance of prefacing the study of physiology proper with a study of the chemistry of the body and of the food.

**Arrangement of Topics.**—The topics treated of in this work will therefore be arranged in the following order: I. Histology of the Human Body; II. Physiologic Chemistry; III. Nutritive Functions; IV. Nervous Functions; V. Reproductive Functions.

# I. HISTOLOGY OF THE HUMAN BODY.

---

ORGANS on minute examination are found to be made up of tissues, or *elementary tissues* as they are sometimes called.

Of elementary tissues there are four: 1. Epithelial; 2. Connective; 3. Muscular; and 4. Nervous.

Some organs contain all four kinds of tissues, while others, more simple in their structure, contain but one or two.

If these tissues are still further analyzed, they are seen to consist of cells or fibers, or of both together in varying proportions: thus the epithelial tissues are made up of cells alone; the connective tissue, principally of fibers; and the nervous, of both cells and fibers.

**Cells** (Fig. 1).—A cell consists of protoplasm, a nucleus, and a centrosome and attraction-sphere. A cell-membrane encloses

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FIG. 1.—Diagram of a cell (Huber).

ing the protoplasm may or may not be present; it is not an essential part of a cell as are the other structures. A centrosome

and attraction-sphere have been found in so many cells that they may be regarded as essential constituents of every cell.

**Protoplasm.**—This is the principal part of a cell, and is of an albuminous nature. Chemically it consists of water (75 per cent. or more), proteids, lecithin, cholesterin, and phosphates and chlorids of sodium, potassium, and calcium, and sometimes fat and glycogen. Microscopically examined it is found to be made up of spongioplasm and hyaloplasm.

**Spongioplasm.**—Under high powers of the microscope the protoplasm of a cell presents the appearance of a fine network, called *reticulum*, *spongework*, or *spongioplasm*. This network has in it knots, which give to it a granular appearance. These knots or granules are of the same chemic nature as the network—that is, are albuminous or proteid. It is still undecided whether these granules are constituent parts of the protoplasm or are its products. Collectively they are denominated *granuloplasm*. Other granules may be present which are not connected with the network, and which are not proteid in character, but fatty or starchy or contain coloring-matter. In some instances they are of an inorganic nature. Granules of this latter kind constitute *paraplasm*; by which is meant any and all material contained in a cell, not being an actual part of it, whether there as pabulum or food for the cell, or as waste material to be excreted.

**Hyaloplasm.**—In the meshes of the spongioplasm is the *hyaloplasm*, a clear substance differing but slightly in its consistence from the spongioplasm, although it is less solid.

**Ameboid Movement.**—Protoplasm is endowed with the power of motion, which from its resemblance to the motion of the ameba, a minute animal, which is but a mass of protoplasm, is called *ameboid*. Examined under the microscope the ameba puts out from its sides projections of its protoplasm—*pseudopodia*; and later the whole mass flows into one or more of these projections, thus changing its position and its shape. This ameboid movement takes place in the white blood-corpuscle, and in some other cells as well as in the ameba. The pseudopodia are frequently drawn back into the protoplasm, or retract, thus illustrating the possession by the protoplasm of *contractility*. Their formation is due to an outflowing of the hyaloplasm, and their retraction to return of the hyaloplasm to the interstices of the reticulum. Ameboid movement is said to be spontaneous; but if so, it can also be produced by the action of heat, by dilute solutions of salt, by moderate currents of electricity, and by many other agents, all of which are called *stimuli*, because of their power to stimulate this movement. On the other hand, certain agents have the power of stopping or inhibiting the movement if it has begun. Thus a temperature above 40° C. or below 0° C. acts as an inhibitant, while if the high temperature is continued the protoplasm is coag-

ulated and its life destroyed. Acids and strong alkalies have the power of destroying the movement altogether, while chloroform inhibits it temporarily. This property of responding to a stimulus is known as *irritability*, and the fact that a stimulus applied to one part of a mass of protoplasm will produce results in other and distant parts demonstrates the presence of *conductivity*.

**Nutrition.**—Another property possessed by living protoplasm is that of *nutrition*; by which is meant the power to absorb material, to convert it into protoplasm, and to get rid of such waste products as have served their purpose or are formed as a result of the activity of the protoplasm. That portion of the process which is concerned in the building up of the protoplasm is *assimilation* or *anabolism*, while that concerned with its breaking down or destruction is *disassimilation* or *katabolism*.

A fourth property of protoplasm is that of *reproduction*, which will be treated of under the heading Division of Cells.

**Nucleus.**—Embedded in the protoplasm is a vesicle of various shapes—spherical, oval, or irregular—which is to be regarded as of great importance, especially in the process of cell-subdivision by which new cells are formed and growth thus brought about. It consists of an external enveloping membrane, the *nuclear membrane*, enclosing the *chromoplasm* or *intranuclear network*, a material resembling spongioplasm, and in the interstices of this is the *nuclear matrix*. In addition to these there are *nucleoli*, some of which are thickenings of the network like the knots in the spongioplasm, and are called *pseudonucleoli*, while others are free, the latter being the nucleoli proper, or the *true nucleoli*. A single true nucleolus is usually found, although this is not always the case.

**Chromatin and Achromatin.**—When cells are stained with hematoxylin the nuclear membrane, the chromoplasm, and the nucleoli take up the staining-fluid readily, while the nuclear matrix does not; hence the former are said to be made up of *chromatin*, or to be *chromatic*; while the latter is *achromatin*, or is said to be *achromatic*. Other dyes, such as safranin, methyl-green, and carmine, produce the same effect. Chromatin is but another name for nuclein, which is the principal constituent of the nucleus. It is closely allied to the proteids, but is characterized by containing a considerable percentage of phosphorus; some analyses give as much as 8 per cent. Nuclein is a compound of nucleic acid with proteids, and it is to the affinity of this acid for the coloring-matter that the staining of chromatin is due. It is more correct to speak of nucleins rather than of a single substance, as the composition of nuclein is not always the same. For a further discussion of this subject the reader is referred to the chapter dealing with Proteids.

**Centrosome.**—As already stated, this is probably to be regarded

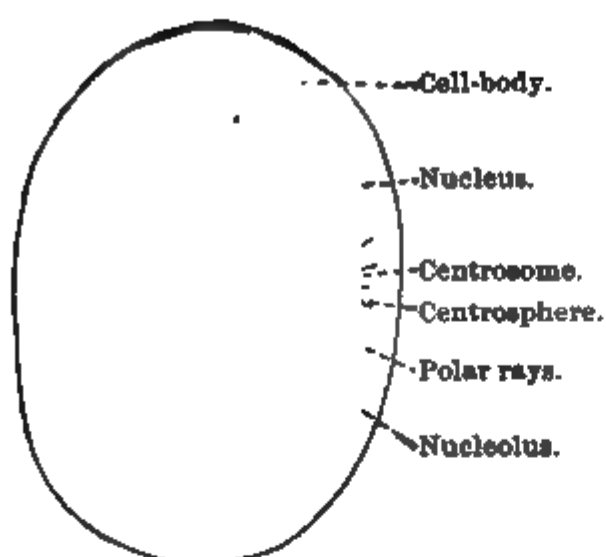


FIG. 2.

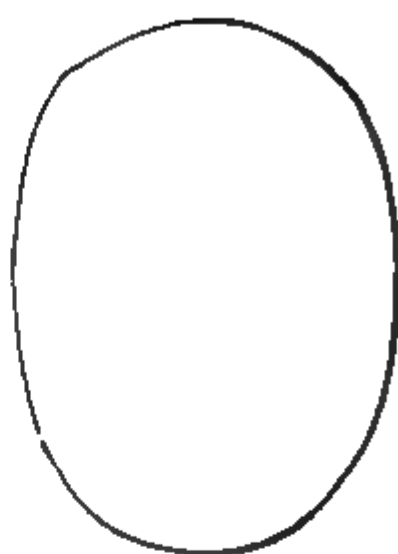


FIG. 3.

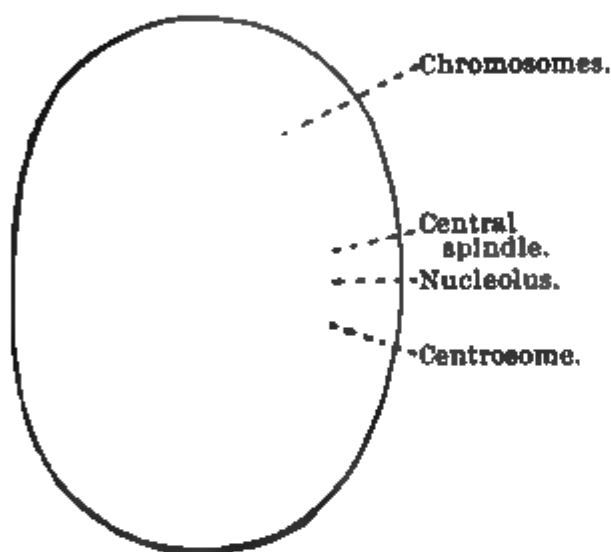


FIG. 4.

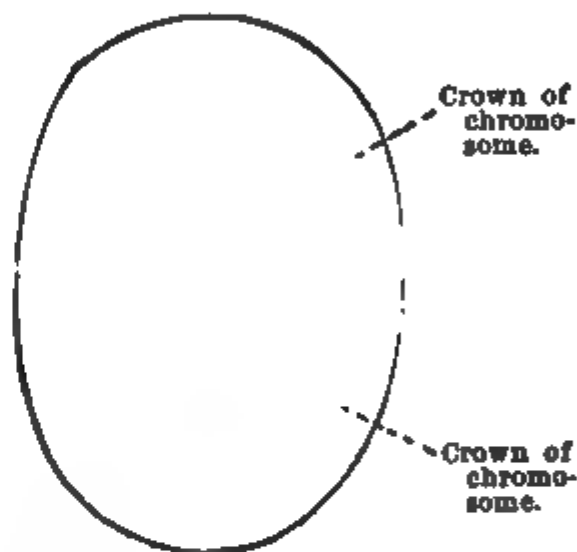


FIG. 5.

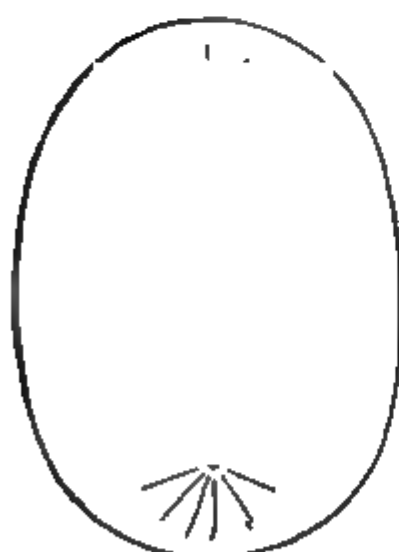


FIG. 6.

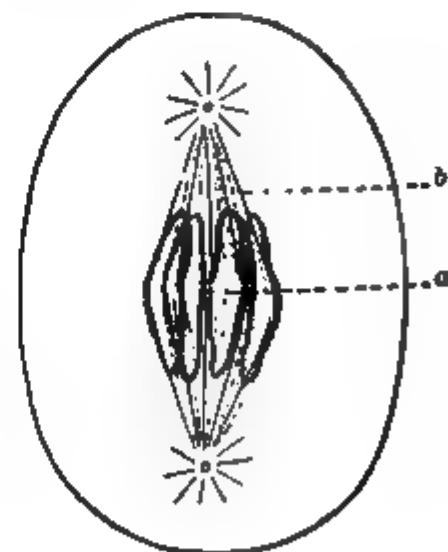
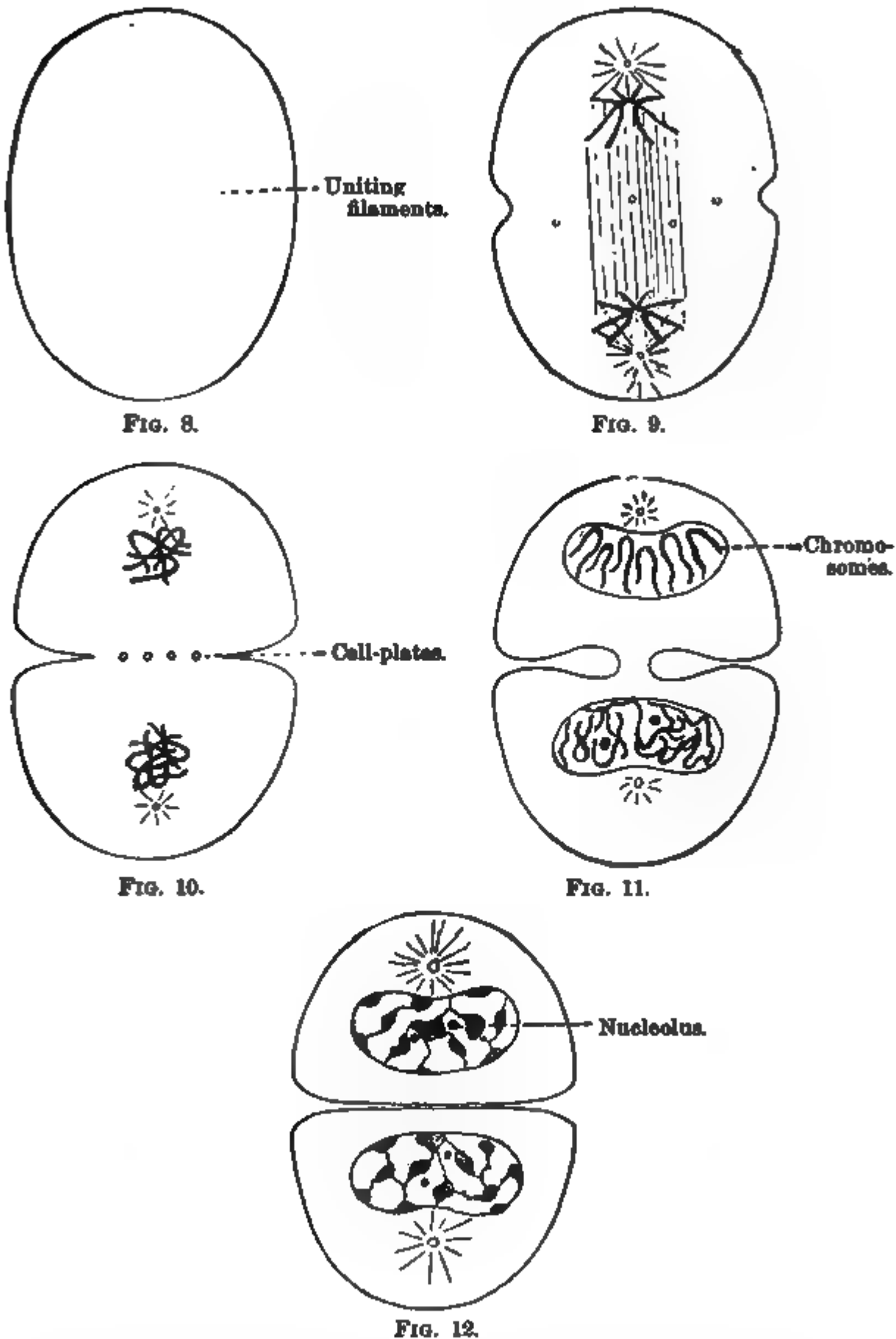


FIG. 7.

FIGS. 2-7.—Diagrammatic representation of the processes of mitotic cell- and nuclear division (Böhm and Davidoff).

FIGS. 2-4, Prophases; FIGS. 6, 7, metaphases.

FIG. 2, Resting nucleus; FIG. 3, coarse skein or spirem; FIG. 4, fine skein or spirem; FIG. 5, segmentation of the spirem into single chromosomes; FIG. 6, longitudinal division of the chromosomes; FIG. 7, bipolar arrangement of the separated chromosomes.



FIGS. 8-12.—Diagrammatic representation of the processes of mitotic cell- and nuclear division (Böhm and Davidoff).

FIGS. 8-11, Anaphases; FIG. 12, telophases.

FIG. 8, wandering of the chromosomes toward the poles; FIG. 9, diaster; FIGS. 10 and 11, formation of the dispirem; FIG. 12, two daughter-cells with resting nuclei. To simplify the figures 5-10, we have sketched in only a few chromosomes. In FIG. 9 it is seen that the cell-body is also beginning to divide.



as an essential element of the cell, inasmuch as the more the subject is investigated the more frequently is this structure found. It is also known by the name of *attraction-particle*. Radiating from it as a center are fine fibers, which together with it constitute the *centrosphere* (Fig. 2). Usually there are two of these spheres in a cell; especially is this the case when the cell is about to divide, and they are connected by fibers forming an *achromatic* or *central spindle*.

**Division of Cells.**—Cells divide and then multiply in two ways: 1. By direct division; 2. By indirect division.

**Direct Division of Cells.**—This may be either by *gemination* or by *fission*. In the former a portion of the nucleus and protoplasm forms a bud-like projection from the parent cell, from which it subsequently separates. The bud develops into a cell similar in all respects to that from which it had its origin. In *fission* the original nucleus divides into two, and then the protoplasm divides in such manner that each half shall possess its own nucleus, and two new cells are thus produced. Direct division is, however, not the method by which cells, as a rule, reproduce their kind; indeed, it is regarded as very infrequent.

**Indirect Division, Karyokinesis, Karyomitosis, Mitosis** (Figs. 2–17).—It is to this method of division that we must look for the comprehension of the processes by which the tissues produce and reproduce themselves. It has been studied in them all—epithelial, connective, muscular, and nervous. While in direct division the nucleus divides into two equal halves, in karyokinesis the changes which take place in the nucleus are complicated, and it is only after a long series that new cells are produced.

The statement is made by some authors that the division of a cell is preceded by the division of its attraction-sphere, and that the division of the nucleus follows; indeed, some regard the change taking place in the attraction-sphere as determining or causing the division of the nucleus; but inasmuch as instances have been observed in which the nuclear changes preceded, they are evidently not under all circumstances dependent upon the influence of the attraction-sphere.

The changes which take place in the process of karyokinesis may be concisely described as follows: Prior to the beginning of the process the cell consists of protoplasm containing a nucleus, with one or more contained nucleoli, and enclosed by the nuclear membrane, and a centrosome and attraction-sphere. A close examination of the chromoplasm of the nucleus shows it to be made up of some fibers which form loops at the ends or poles of the nucleus, and are the primary loops, while others less prominent and which help to give to the chromoplasm its reticular or network form are secondary fibers.

When indirect division begins the first change usually, though

not always, consists in the division of the centrosome and of the attraction-sphere into two; then the following changes take place in the nucleus: The nucleoli and the secondary fibers disappear, while the primary loops remain as chromosomes. These latter become less twisted, forming a *spirem* or skein, and split into two sets, forming a *dispirem* or double skein, thus doubling the number

FIG. 13.

FIG. 14.

FIG. 15.

FIG. 16.

FIG. 17.

FIGS. 13-17.—Mitotic cell-division of fertilized whitefish eggs—*Coregonus albus* (Huber).

FIG. 13, Cell with resting nucleus, centrosome, and centrosphere to the right of the nucleus; FIG. 14, cell with two centrospheres, with polar rays at opposite poles of nucleus; FIG. 15, spirem; FIG. 16, monaster; FIG. 17, metakinesis stage.

of chromosomes (Fig. 10, 11). The number of chromosomes is subject to considerable variation in different animal cells. In some, four have been seen, in others as many as twenty-four.

The *achromatic spindle* (Fig. 6) now appears. This consists of a spindle-shaped structure, at each end of which is a centrosome, the two having been formed from the original centrosome of the cell. These are connected by achromatin fibers—*i. e.*, fibers which are not colored by the staining-material used in the study

of the karyokinetic process. Whether these fibers are formed from the attraction-sphere or from the achromatin of the nucleus is unknown. Each of these centrosomes forms a pole of the spindle. The nuclear membrane now disappears, and there is nothing between the protoplasm of the cell and the nuclear matrix. The protoplasm in contact with the nucleus is clear, while that outside of this clear space is granular. In some cells these granules have the appearance of fine fibers radiating from the centrosomes or poles, and constitute the *amphiaster*.

The next stage is characterized by the settling of the chromosomes to the equator of the spindle, where they form a star or *aster*, which being single is called *monaster*: this is known as the *equatorial stage*.

The chromosomes now separate so as to form two distinct groups, constituting the stage of *metakinesis*. One group passes to one end or pole and the other to the other, thus forming a star at each end and giving rise to the term *diaster* or double star. This passage of the chromosome from the equator to the poles is believed to be accomplished by the contraction of the achromatin fibers of the spindle. Thus from the chromoplasm of the nucleus two new nuclei, or daughter-nuclei, are formed, each aster passing into a resting nucleus by a process the reverse of that by which it was formed, through the *dispirem* stage. A nuclear membrane forms around each new nucleus, and the protoplasm of the original cell subdivides into two, each half enclosing a new nucleus: at the same time the spindle disappears.

## ELEMENTARY TISSUES.

### EPITHELIAL TISSUE.

Distributed over the surface of the body, lining its many cavities and canals, and in the ducts of glands, epithelium is found of several varieties and arrangement. The varieties are as follows: Pavement or scaly, cubical, columnar, goblet-cell, spheroidal or glandular, and ciliated.

**Pavement or Scaly Epithelium** (Fig. 18).—As its name implies, the cells of this variety of epithelium are thin and flat, and are arranged like the stones of a pavement. They are bound together by a small amount of cement-substance. They are found in the lung-alveoli, in the ducts of the mammary glands, and in the kidney in the tubes of Henle, and lining Bowman's capsules. These cells are also found covering serous membranes, as the pericardium, and lining blood-vessels and lymphatics, and in that case receive the name of *endothelium*.

**Cubical Epithelium.**—This kind of epithelium is of a

cubical shape, and occurs in the tubules of the testis and in the alveoli of the thyroid gland.

FIG. 18.—Isolated cells of squamous epithelium (surface cells of the stratified squamous epithelium lining the mouth): *a, a*, cells presenting under surface; *b*, cell with two nuclei (Huber).

**Columnar Epithelium** (Fig. 20).—Columnar epithelium is sometimes described as *cylindric epithelium*. The cells are of a prismatic shape, and usually rest upon a basement-membrane. When looked at from the free end, they present the appearance of a mosaic; when observed from the side, the free edge is seen to be striated.

This variety of epithelium lines the stomach and intestines, and the glands which open into these cavities. It covers the mucous membrane of most of the urethra, the vas deferens, prostate, Cowper's glands, and the ducts of most glands. The *germinal epithelium* which covers the ovary is of this type.

**Goblet-cell** (Fig. 22).—A peculiar modification of columnar

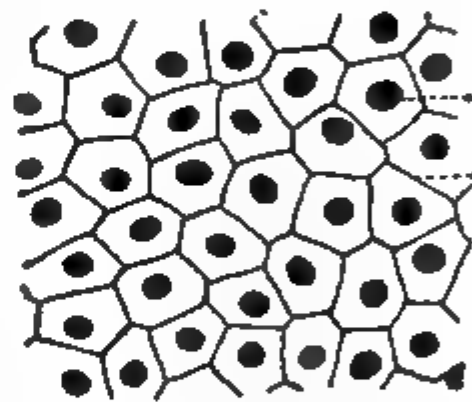
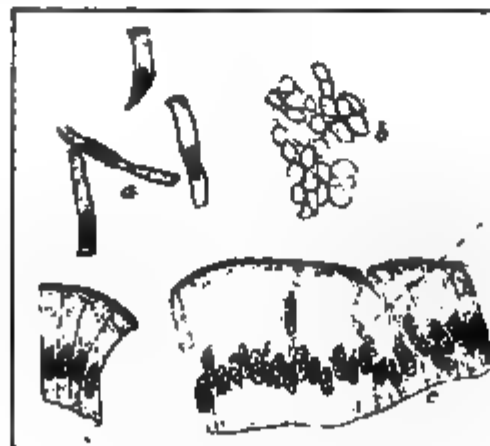


FIG. 19.—Surface view of squamous epithelium from skin of a frog;  $\times 400$  (Böhm and Davidoff).



Goblet-cell.

Cuticular border.

FIG. 20.—Simple columnar epithelium from the small intestine of man: *a*, isolated cells; *b*, surface view; *c*, longitudinal section (Huber).

epithelium is seen in the *goblet-cell*. This occurs in the intestine, for example; the mucin, which is the product of the cell, distends the upper part of it, and the cell bursts (Fig. 22). The mucin is discharged as mucus, and the open, cup-like end of the cell gives to it the peculiar appearance characteristic of the goblet-cell.

Goblet-cell.

—Cilia.

FIG. 21.—Cross-section of stratified ciliated columnar epithelium from the trachea of a rabbit (Huber).

Formerly regarded as a simple modification of the columnar cell, these goblet-cells are probably more properly to be considered as a special kind of epithelium which is of a permanent nature, and whose function is to secrete mucus; hence they are sometimes called *mucus-secreting cells*.

**Spheroidal or Glandular Epithelium.**—This is characterized by its polyhedral or spheroidal shape, and occurs in secreting

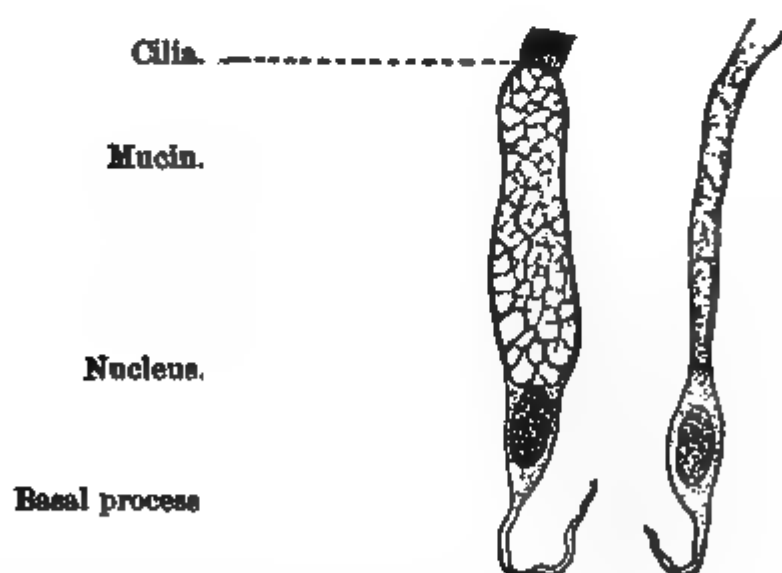


FIG. 22.—Goblet-cells from the bronchus of a dog: the middle cell still possesses its cilia; that to the right has already emptied its mucous contents (collapsed goblet-cell);  $\times 600$  (Böhm and Davidoff).

glands; as, the salivary glands, liver, and pancreas. The secretion of these glands is the product of the protoplasm of the glandular epithelium.

**Ciliated Epithelium** (Fig. 23).—The characteristic of this variety is the cilia or hair-like or eyelash-like appendages attached

to the free surface of the cells. The cells which bear the cilia are usually of the columnar variety.

Ciliated epithelium covers the mucous membrane of the respiratory tract, which begins with the nose and ends in the alveoli of the lung, with the following exceptions: The olfactory membrane (that part of the mucous membrane of the nose to which the olfactory nerves are distributed), the lower part of the pharynx, the surface of the vocal cords, the ultimate bronchi, and the lung-alveoli. It covers also the mucous membrane of the tympanum, except the roof, promontory, ossicles, and membrana tympani, where the epithelium is of the pavement variety and non-ciliated. Ciliated epithelium occurs also in the Eustachian tube, the Fallopian tube, the cavity of the body of the uterus and of the upper two-thirds of the cervix, the vasa efferentia and coni vasculosi of the testicle, the ventricles of the brain, and the central canal of the spinal cord. Some observers have seen ciliated epithelium in the convoluted tubules of the kidney.

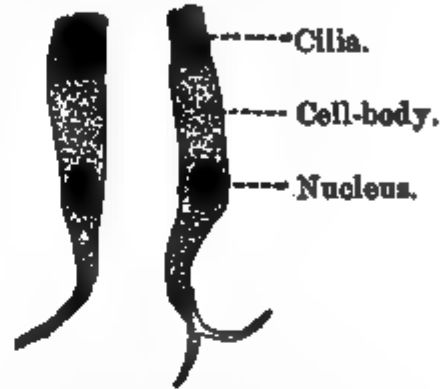


FIG. 23.—Ciliated cells from the bronchus of the dog, the left cell with two nuclei;  $\times 600$  (Böhm and Davidoff).

**Ciliary Motion.**—Cilia are composed of protoplasm, and, like other protoplasm, have the power of motion; but ciliary motion, though in some respects like that known as ameboid, is in other respects quite different. Instead of being slow, it is very rapid—ten times and more a second—so much so that when active, the individual cilia which produce it are indistinguishable. It has been likened to the movement of a field of wheat over which a breeze is passing. The effect of this movement is to produce a current always in one direction, and this current is often of considerable physiologic importance: thus it is to its influence that the ovum is carried down the Fallopian tube in the human female; and, according to some authors, were it not for the ciliated epithelium in this canal the ovum would not find its way into the tube, but at the time it escapes from the ovary would fall into the peritoneal cavity and degenerate.

Various explanations have been given to account for ciliary motion. One which seems reasonable is that it is due to the same cause which produces ameboid movement, namely, the flow of the hyaloplasm into and out of the spongioplasm. It is a well-known fact that if cilia are severed from the cells of which they form a part, this motion ceases, so that intimate connection with the

cells is essential. The protoplasm composing the cilia being thus in direct communication with that of the epithelium, being in fact a prolongation of it, the hyaloplasm can flow in and out without hindrance; the inflow causing them to straighten, the outflow causing them to resume their original condition, which is curved; this rapid inflow and outflow produce the characteristic motion.

External agencies affect this motion as they do that of other protoplasm. Chloroform inhibits it, as do temperatures above 40° C. or below 0° C.; while dilute alkalies favor it.

**Simple Epithelium.**—When epithelium of either of these varieties is arranged in a single layer it is known as *simple epithelium*.

**Stratified Epithelium** (Fig. 21).—When the epithelial cells are arranged in many layers they form *stratified epithelium*, the cells of each layer differing in shape. Thus in the epidermis, the epithelium of which is of this variety, the deepest layer is columnar in character; next to this is a granular layer of spindle-shaped cells; then one of closely packed cells; and, most superficial of all, are several layers of dry, horny scales.

Stratified epithelium is also found covering the mucous membrane of the mouth, the lower part of the pharynx, the esophagus, vagina, and outer third of the cavity of the cervix uteri, and the conjunctiva.

**Transitional Epithelium.**—This term is applied to epithelium which is arranged in a few layers—two, three, or four. The line of demarcation between stratified and transitional epithelium is not very distinct. This variety exists in the ureters and bladder in three layers. The inner layer is composed of cuboidal cells, the next of pear-shaped cells, between the lower elongated ends of which is a third layer of small cells.

The hair, the nails, and the enamel of the teeth are of an epithelial nature, though in a much modified form. Epithelium is nourished by lymph, and with few rare exceptions is not supplied with nerves: such exceptions are the epithelium covering the cornea and that in the deep layers of the epidermis.

## CONNECTIVE TISSUE.

The term “connective” as applied to this large group of tissues implies that they are concerned in binding the body together into one organic whole, without which the tissues would be disconnected and the body lack the support which these structures afford. The following are the varieties: 1. Areolar; 2. Adipose; 3. Retiform; 4. Lymphoid; 5. Elastic; 6. Fibrous; 7. Jelly-like; 8. Cartilage; 9. Bone; 10. Dentin.

**Areolar Tissue.**—Areolar tissue consists of bundles of fibers presenting a wavy appearance (Fig. 24) running in various direc-

tions, together with elastic fibers (Fig. 25) which do not form bundles and are not wavy. These fibers are bound together by a cementing-material or ground-substance. The irregular crossing of the fibers leaves spaces, called *areolæ*, which give the name to the tissue. In these are *connective-tissue cells* or *corpuscles*, of which there are several varieties, the protoplasm of which produces the fibers and the ground-substance. These varieties are:



FIG. 24.—Cell-spaces in the ground-substance of areolar connective tissue (subcutaneous) of a young rat; stained in silver nitrate (Huber).

FIG. 25.—Elastic fibers from the ligamentum nuchæ of the ox, teased fresh;  $\times 500$ . At *a* the fiber is curved in a characteristic manner (Böhm and Davidoff).

1. *Lamellar cells*; 2. *Plasma-cells* of Waldeyer; 3. *Granule-cells*. Lymph-corpuscles are not infrequently seen, and in some places, as in the choroid coat of the eye, the corpuscles contain coloring-matter or pigment.

Areolar tissue occurs under the skin as subcutaneous tissue, beneath serous membranes as subserous, and beneath mucous mem-



Nucleus.  
Protoplasm.

Fat-drop.  
Cell-membrane.

FIG. 26.—Scheme of a fat-cell (Böhm and Davidoff).

branes as submucous, connecting these membranes loosely to the structures upon which they lie. Enclosing muscle, blood-vessels, and nerves, it forms their *sheaths*. It is also found in glands connecting the various parts with one another.

**Adipose Tissue** (Fig. 27).—When the areolæ of areolar tissue contain fat-cells, the tissue is called *adipose*. These *fat-cells* or *adipose vesicles* consist of an envelope or sac, protoplasmic



in character, within which is the fat in a fluid form. The temperature of the body during life is believed to keep this fat fluid ;

FIG. 27.—Adipose tissue (Leroy) : a, fibrous tissue ; b, fat-cells ; c, nucleus of fat-cells ; d, fatty acid crystals in fat-cells.

but after death, when the temperature falls, the fat becomes solid. Free adipose vesicles would doubtless assume a spheroidal

lum.

is of  
ec-  
tissue

1.

FIG. 28.—Reticular connective tissue from lymph-gland of man ; Brush preparation (Böhm and Davidoff).

shape, but by compression, either of contiguous vesicles or other structures, they assume various shapes, oval or polyhedral.

**Adipose tissue** is widely distributed through the body; indeed, it is an exception to find areolar tissue without some fat in its areolæ. The principal exceptions are the areolar tissue beneath the skin of the eyelids, the penis, the scrotum, and the labia minora. There is also no adipose tissue within the cranium, in the liver, or in the lung, except near its root. It is to be understood that this statement does not apply to fat, but to adipose tissue, which is characterized by the fact that the fat is enclosed in a protoplasmic envelope. The fat is formed from the protoplasmic connective-tissue corpuscles, the cell-wall of which forms the wall of the vesicle. The nucleus of the cell remains, although it is not always readily discernible.

**Retiform Tissue** (Fig. 28).—This may be defined as areolar tissue whose ground-substance is fluid, and in which but few, if any, elastic fibers exist, and the white fibers form a close network. Authorities differ as to the identity of the white fibers of areolar and those of retiform tissue; some claim that their different behavior to certain reagents demonstrates them not to be the same. Retiform tissue exists in mucous membranes.

**Lymphoid Tissue**.—When the areolæ of retiform tissue contain lymph-corpuscles, which will be described in connection with the blood, the tissue is *lymphoid* or *adenoid*. It is found in lymphatic glands, the thymus gland, the tonsils, solitary glands, patches of Peyer, and Malpighian corpuscles of the spleen.

**Elastic Tissue** (Fig. 25).—This tissue is composed of fibers or membranes which are characterized by their elasticity and a yellow color. By elasticity is defined "that property of matter by virtue of which a body tends to return to a former or normal size, shape, or attitude, after being deflected or disturbed."

The tissue exists in the ligamenta subflava of the vertebræ, the vocal cords, between the cartilages of the larynx, in the longitudinal coat of the bronchi, the lungs, the middle coat of the larger arteries (such as the aorta and caro-

Tendon-cell.

Tendon-fibers.

FIG. 29.—Longitudinal section of tendon;  $\times 270$  (Böhm and Davidoff).

tids), and in the stylohyoid, thyrohyoid, and cricothyroid ligaments.

**Fibrous Tissue** (Fig. 29).—By reason of its color this kind of tissue is also called *white fibrous tissue*. It is made up of white and glistening non-elastic fibers, which give to it great strength. It is widely distributed, occurring in ligaments, tendons, muscular fascia, periosteum, perichondrium, pericardium, and dura mater, sclerotic coat of the eye, tunica albuginea of the testis, capsule of the kidney, epineurium, and the sheaths of the corpora cavernosa and corpus spongiosum of the penis. In the ligaments and tendons the fibers are arranged in bundles, between which are many flat connective-tissue corpuscles, the *tendon-cells* (Fig. 29).

a

Matrix.

Cartilage-  
cell.

FIG. 30.—Hyaline cartilage (costal cartilage of the ox); alcohol preparation;  $\times 300$  (Böhm and Davidoff). The cells are inclosed in their capsules. In the figure a are represented frequent but by no means characteristic radiate structures.

**Jelly-like Connective Tissue.**—This consists of a soft matrix, with a few spheroidal cells and a few fibers. It is found in the embryo, as in the jelly of Wharton in the umbilical cord. The only structure in the adult made of this material is the vitreous humor of the eye. It consists chemically of water and mucinogen, with a small amount of proteid and salts.

**Cartilage.**—This tissue exists in the human body in several varieties; a. Hyaline; b. White fibrous; c. Yellow elastic; d. Cellular.

**Hyaline Cartilage** (Fig. 30).—This variety is sometimes called *true cartilage*. It varies in structure according to the location in which it occurs, and by reason of this its location receives different names: *articular* and *costal*.

*Articular Cartilage* (Fig. 31).—The cartilage-cells of this variety are usually arranged in small groups in a ground-substance or *matrix*, which is clear except when examined under a high power of the microscope, when it appears granular. In this matrix there are no fibers except at the edges, where some fibers may be found and where the cells are branched. At the edges the cartilage is in

White fibrous connective tissue.

White fibrocartilage.

Insertion of ligamentum teres.

Hyaline cartilage.

FIG. 31.—Insertion of the ligamentum teres into the head of the femur; longitudinal section;  $\times 650$  (Böhm and Davidoff).

communication with the *synovial membrane* (Fig. 31), and the cells of the cartilage are branched and resemble the branched cells of the connective tissue of the synovial membrane, from which fact they give to the cartilage the name *transitional*. Although hyaline cartilage is described as having a matrix free from fibers, still, under proper treatment, a fibrous character can be made out.

Articular cartilage covers the ends of bones in the joints

Fig. 31), where it serves the double purpose of reducing concussion by virtue of its elasticity, and of forming a smooth surface for the motion of the joint. It has no blood-vessels, but is nourished from both the synovial membrane and the bone. It does not ossify—that is, become bone.

*Costal Cartilage* (Fig. 30).—Cartilage of this kind is hyaline, though in old age a fibrous character is observed. Its individual cells are larger, and the groups of them are larger than in articular cartilage. Its tendency to ossify is another difference when compared with the articular variety. *Ossification* and *calcification* must be very carefully distinguished. In the former a formation

artilage-cell.

lastic fibers.

FIG. 32.—Elastic cartilage from the external ear of man: a, fine elastic network in the immediate neighborhood of a capsule;  $\times 760$  (Böhm and Davidoff).

of bone occurs; in the latter there is simply a deposition of lime salts.

Costal cartilage is found in connection with the ribs, and also in the larynx, excepting in those minute structures, the *cornicula laryngis* or the *cartilages of Santorini*. It also forms the cartilaginous structure in the trachea, the nose, and the external auditory meatus.

*White Fibrous Cartilage* or *Fibrocartilage* (Fig. 31).—White fibrous connective tissue, with cartilage-cells between the bundles, characterizes this tissue. It is described as of four kinds, principally by reason of the office it serves; *interarticular*, flat plates between

the articular cartilages of some joints, as the knee and the wrist; *connecting*, as between the bodies of the vertebræ; *circumferential*, as in the cotyloid cavity of the hip-joint, which it makes deeper; and *stratiform*, where it lines grooves in bone through which tendons pass. It also occurs in some tendons, as in that of the peroneus longus.

**Yellow Elastic Cartilage** (Fig. 32).—The presence of elastic fibers in the matrix is the distinguishing feature of this variety of cartilage, which is found in the pinna of the ear, the Eustachian tube, the epiglottis, and the cornicula laryngis.

**Cellular Cartilage**.—This kind is made up almost wholly of cells; sometimes fine fibers are present. The only structure in which it is found in the human body is the *chorda dorsalis* or *notochord* of the embryo.

**Chemical Composition of Cartilage**.—The following analyses were made by Hoppe-Seyler, and represent parts per 1000:

	Costal Cartilage.	Articular Cartilage.
Water . . . . .	676.6	735.9
Solids, organic . . . . .	301.8	248.7
Solids, inorganic . . . . .	22.0	15.4
	<hr/> 999.9	<hr/> 1000.0

**Organic Solids of Cartilage**.—The cells contain, besides the proteid contents of cells generally, fat and glycogen. The matrix contains chondrigen, which on boiling yields chondrin. This is the generally accepted theory as to cartilage, but the most recent analyses seem to show that chondrin is not a simple substance, but a mixture, and that in the matrix are four substances: 1. *Collagen*; 2. An *albuminoid*, which exists only in later adult life, and is like elastin, but contains more sulphur; 3. *Chondromucoid*; and 4. *Chondroitin-sulphuric acid*.

**Inorganic Solids of Cartilage**.—Potassium and sodium sulphates, sodium chlorid, and sodium, calcium, and magnesium phosphates represent the inorganic class of physiologic ingredients of cartilage.

**Perichondrium**.—This is a fibrous membrane which envelops cartilage except at the articular ends of bones: it contains blood-vessels, which assist in nourishing the cartilage.

**Bone**.—There are two varieties of bone: *compact* and *cancellous* or *cancellated*. The former is firm and dense, and occurs on the exterior of bones; the latter is spongy and more open in structure, and occupies the interior. The differences between the two are not such as to justify their being regarded as two distinct varieties, for in all essential points they are identical. Practically, however, it seems wise to describe them separately. When a cross-section of a bone is examined under the microscope (Fig. 33) *Haversian canals* are seen, averaging 0.05 mm. in diameter:

around these the bone is arranged in rings, *lamellæ*; between these are spaces, *lacunæ*, in which are *bone-corpuscles* (Fig. 34). Each canal is connected with the *lacunæ* which are concentric

Outer circum-  
ferential  
lamellæ.

Haversian or  
concentric  
lamellæ.

Haversian  
canal.

Interstitial  
lamellæ.

Inner circum-  
ferential  
lamellæ.

FIG. 33.—Segment of a transversely ground section from the shaft of a long bone, showing all the lamellar systems; metacarpus of man;  $\times 56$  (Böhm and Davidoff).

with it, and the *lacunæ* with one another by means of fine canals, *canaliculi*, into which project processes of the bone-corpuscles. A Haversian canal (Fig. 34) with its lamellæ, *lacunæ*, bone-

corpuscles, and canaliculi form a *Haversian system*. In a section of bone several of these systems may be seen, the spaces between them being occupied by *interstitial lamellæ*. Lamellæ which are on the surface of the bone, parallel with its circumference, are *circumferential lamellæ*. A longitudinal section of bone shows the Haversian canals to be what their name indicates, channels running through the bone. Their communication with one another is also seen. In each canal are an artery and a vein.

If a piece of bone is treated with dilute nitric acid, so as to dissolve the lime salts which it contains, or by some other method of *decalcification*, a small portion may be torn off, which upon examination shows the fibrous structure of the lamellæ. Such specimens also show the *perforating fibers of Sharpey*, which hold the lamellæ together; elastic fibers may also be observed.

L  
Canal  
  
Haversian

FIG. 34.—Portion of a transversely ground disk from the shaft of a human femur;  $\times 400$  (Böhm and Davidoff).

**Periosteum.**—This is a fibrous membrane which encloses the bones except where covered by cartilage. It is made up of an outer layer of connective tissue, in which there are blood-vessels which give off branches that go to the Haversian canals; and an inner layer, in which elastic fibers are present. Between the periosteum and the bone in young animals are nucleated cells, the *osteoblasts* or *bone-forming cells*.

**Bone-marrow.**—Marrow is of two kinds, yellow and red. The *yellow marrow* is found in the interior of the shafts of long bones, in the *medullary canal*, and consists of fibrous tissue in which are blood-vessels and cells, fat-cells principally, although some *marrow-cells* and *myeloplaxes* also occur. The composition of yellow marrow is: fat, 96 per cent. (no other structure of the body containing so much, adipose tissue containing but 82.7 per cent.); areolar tissue, 1 per cent.; and 3 per cent. of fluid. *Red marrow* (Fig. 35) occurs in flat and short bones, the articular ends of long bones, bodies of vertebræ, cranial diploë, sternum, and ribs. In structure it resembles yellow marrow, except that fat-cells are few, while marrow-cells are very abundant. Chemically it is composed of



75 per cent. water and 25 per cent. solids; the latter consisting of salts, a very small amount of fat, and two proteids, one a cell-globulin coagulating at 47°–50° C. and a nucleoproteid containing 1.6 per cent. of phosphorus. Hemoglobin is also present.

**Marrow-cells** (Fig. 36).—The cells of red marrow are of four kinds: 1. *True marrow-cells*, which are round, nucleated cells like white blood-corpuscles, but larger, and exhibiting ameboid motion. 2. *Erythroblasts*, pinkish in color, and in appearance like the nucleated red blood-corpuscles of the embryo. Some authorities regard these latter as cells which are originally true marrow-cells and afterward become red blood-corpuscles; while others hold that they are never marrow-cells, but have come directly from the nucleated blood-cells of the embryo and become red blood-corpuscles, the nuclei disappearing. In the erythroblasts the process of karyokinesis may often be observed. 3. *Myeloplaxes*; these cells are also called *giant cells*, *myeloplaques*, and *osteoclasts*. These are very large nucleated cells, which are also found in the yellow marrow of the adult. 4. Cells which contain red blood-corpuscles in various stages of transformation into pigment, resembling the large cells found in the spleen, and called *splenic cells*.

**Blood-vessels of Bone.**—The periosteum sends branches of its blood-vessels into the compact tissue, some passing into the Haversian canals, while others continue on and supply the cancellous tissue in the interior. In the middle of the long bones is an opening, the *nutrient foramen*, through which passes the *medullary* or *nutrient artery*, with one or two veins, traversing the compact tissue to reach the medullary canal, where it supplies the tissue contained therein. Similar openings exist in other bones for the transmission of blood-vessels to their interior. It is claimed by some that the walls of the capillaries in the marrow are imperfect, and that through the openings which exist the red blood-corpuscles produced in the marrow find their way into the blood-circulation.

**Lymphatic Vessels of Bone.**—These are found in the periosteum and the bone-substance, and also in the Haversian canals.

**Nerves of Bone.**—The periosteum is supplied with nerves, and they also pass into bones through the nutrient foramina. Especially rich in nerves are the articular extremities of long bones, the vertebræ, and the larger flat bones.

**Chemical Composition of Bone.**—Hoppe-Seyler gives the following analysis of undried bone without separation of marrow or blood:

Water . . . . .	50.00 per cent.	Ossein (or collagen) . . . . .	11.40 per cent.
Fat . . . . .	15.75 " "	Bone earth . . . . .	21.85 " "

The following is Zalesky's analysis of human dried macerated bone:

Organic constituents . . . . .	34.56 per cent.
Inorganic " . . . . .	65.44 " "
	<hr/> 100.00

Gray states that the organic constituent of bone forms about 33 per cent., and the inorganic 66.7 per cent. He quotes the following analysis of Berzelius:

Organic matter . . . .	Gelatin and blood-vessels .	88.80 per cent.
Inorganic or earthy .	Phosphate of lime . . . .	51.04 " "
	Carbonate " . . . .	11.80 " "
	Fluorid of calcium . . . .	2.00 " "
	Phosphate of magnesium .	1.16 " "
	Soda and chlorid of sodium,	1.20 " "

The organic constituents are ossein, also called collagen; elastin, proteids, and nuclein form the bone-corpuscles, with a small quantity of fat. The inorganic constituents are calcium phosphate,

*c*

FIG. 35.—From a section through human red bone-marrow: *a, f*, normoblasts; *b*, reticulum; *c*, mitosis in giant cell; *d*, giant cell; *e, h*, myelocytes; *g*, mitosis; *i*, space containing fat-cells;  $\times 680$  (Böhm and Davidoff).

carbonate, chlorid, and fluorid; magnesium phosphate, sodium chlorid, and some sulphates. Of these inorganic constituents, calcium phosphate exists to the amount of 83.88 per cent., and calcium carbonate to the amount of 13 per cent.

**Development of Bone.**—*Ossification*, the process by which bone is formed, occurs in two forms: *intramembranous* and *intracartilaginous* or *endochondral*. The subperiosteal variety described by some authors is, in all essential particulars, identical with the intramembranous. By the intramembranous are formed the parietal, frontal, and upper portions of the tabular surface of the

occipital bone; while by the intracartilaginous, the humerus, femur, and other long bones are formed.

*Intramembranous Ossification* (Fig. 37).—This process may be studied in the parietal bone, which, prior to the beginning of ossification, about the seventh or eighth week of fetal life, is a fibrous membrane containing blood-vessels and osteoblasts (Fig. 37). The process begins in the *center of ossification*, which, in the parietal bone, is single, at the parietal eminence. The number of these centers varies in different bones; in the frontal there are two.

The embryonic membrane is composed of bundles of fibers, *osteogenic fibers*, with a granular matrix between them. Both the

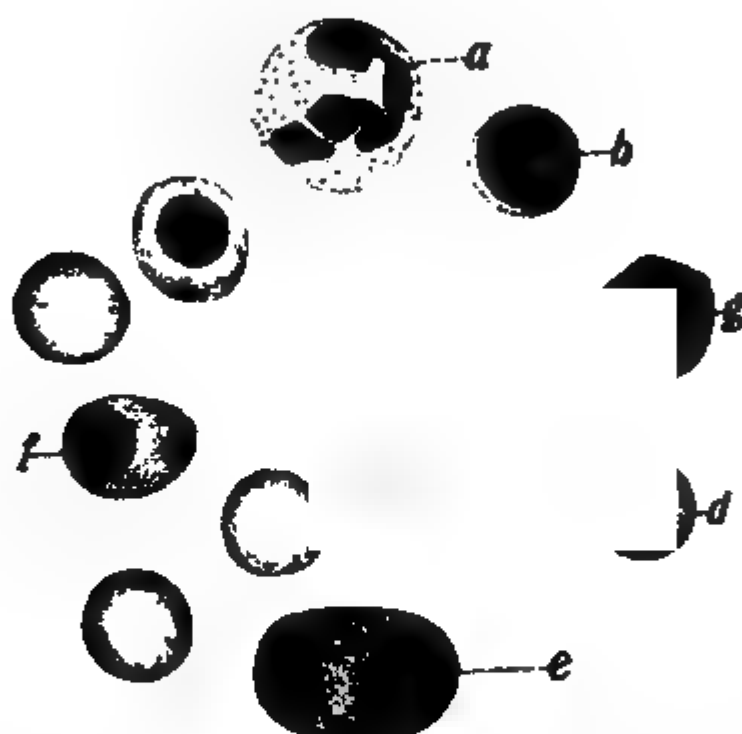


FIG. 36.—Cover-glass preparation from the bone-marrow of dog;  $\times 1200$  (from preparation of H. F. Müller) (Böhm and Davidoff): *a*, mast-cell; *b*, lymphocyte; *c*, eosinophile cell; *d*, red blood-cell; *e*, erythroblast in process of division; *f, f*, normoblast; *g*, erythroblast. Myelocyte not shown in this figure.

fibers and the matrix become *calcified* by the deposition in them of lime salts, and there is produced in them a calcareous mass enclosing blood-vessels and osteoblasts, which latter become bone-corpuscles, and the spaces in which they lie form the lacunæ. The blood-vessels permeate the whole, the channels which they form being Haversian canals. It will be observed that in this variety of ossification a membranous structure precedes the bone; hence the bone is said to be *formed in membrane*.

*Intracartilaginous or Endochondral Ossification* (Fig. 37).—In this form cartilage precedes the bone, and the changes which result in bone-formation take place within it and practically convert it into bone.

*First Stage*.—In the first stage the cartilage-cells at the center

Connective  
tissue.

Outer fibrous  
layer of  
periosteum.

Osteogenetic  
layer of  
periosteum.

Osteoblasts.

Marrow-  
space.

Blood-ves-  
sel.

Osteoblasts.

Remnants of  
cartilage-  
matrix.  
Bone-cells.

Ossous  
matrix.

Osteoblasts.

FIG. 37.—From a cross-section of a shaft (tibia of a sheep);  $\times 550$  (Böhm and Davidoff): in the lower part of the figure is endochondral bone-formation (the black cords are the remains of the cartilaginous matrix); in the upper portion is bone developed from the periosteum.

of ossification become larger and arranged in rows; in the matrix or ground-substance, between these rows of cells, lime salts are deposited in such manner as to form longitudinal rows of cells, separated by the calcified matrix; in the matrix, between

adjacent cells, at right angles to these calcareous columns, lime salts are also deposited, thus forming spaces containing cartilage-cells, the boundaries of which are composed of the calcified matrix. These spaces or cavities are *primary areolæ*. While this process is taking place at the center of the cartilage, beneath the membrane which envelops the cartilage, the perichondrium, or, as it is subsequently called, the *periosteum*, the osteoblasts form fibrous

Vesicular cartilage-cells.

Primary periosteal bone-lamella.

Periosteal bud.

Periosteum.

Unaltered hyaline cartilage

FIG. 33.—Longitudinal section through a long bone (phalanx) of a lizard embryo (Böhm and Davidoff). The primary bone-lamella originating from the periosteum is broken through by the periosteal bud. Connected with the bud is a periosteal blood-vessel containing red blood-corpuscles.

lamellæ on the surface of the bone, which become calcified by the deposit in them of lime salts. Some osteoblasts are closed in by the lamellæ and become bone-corpuscles. These changes which take place on the surface beneath the periosteum constitute subperiosteal or intramembranous ossification, which has already been described; thus, both kinds of ossification take place in the long bones.

*Second Stage or Stage of Irruption.*—In this stage the blood-vessels and osteoblasts of the periosteum form processes which absorb portions of the bone recently made by intramembranous ossification, and of the walls of the primary areolæ, thus producing larger spaces or cavities, *secondary areolæ* or *medullary spaces*; these contain osteoblasts and blood-vessels, which constitute *embryonic marrow*. Authorities differ as to the ultimate fate of the cartilage-cells; some think they become osteoblasts, while others teach that they are absorbed.

*Third Stage.*—The osteoblasts of the embryonic matrix, increased in number by division, form a layer of bone on the surfaces of the walls of the secondary areolæ. On this bony wall another layer of osteoblasts forms a second layer of bone, and thus the process continues until only a small canal remains, the Haversian canal. The layers of bone, produced in the manner described, are the lamellæ; while such of the osteoblasts as remain between the lamellæ become the bone-corpuscles. No satisfactory explanation has been given of the method of production of the canaliculi. During this stage the process of ossification which began in the center of the bone extends toward the extremities, and thus the entire shaft becomes ossified. Histologists describe the multinucleated cells (similar to the myeloplaxes of the marrow) which are concerned in the absorption of the calcified matrix and bone under the name *osteoclasts*, reserving the term osteoblasts for the cells which form the bone.

The shaft of the bone and its extremities remain separated for a period of time which varies in different bones, and increase in length takes place by a growth of cartilage between the shaft and its *epiphyses*. This *intermediate cartilage* later ossifies, and the union of shaft and extremities is complete. Cartilaginous at first like the shaft, the epiphyses undergo ossification in

FIG. 39.—Longitudinal section through area of ossification from long bone of human embryo (Huber).

the same manner. The bone becomes of greater circumference by the deposits made by the periosteum externally, and the medullary canal is made larger by the absorption of a portion of its walls. In the repair of bones, as after fractures, the periosteum performs the same office as in the original formation of bone.

**Dentin.**—The consideration of this substance calls for a description of the teeth, of which it forms an important part.

A tooth (Fig. 40) is divided anatomically into the *crown*, the visible portion, which projects above the gum; the *root*, the portion out of sight within the *alveolus* or socket; and the *neck*, the constricted portion joining the crown and the root. In the center of the crown and extending into the roots is the *pulp-chamber*, the openings of which, at the tip of the roots, are *apical foramina*, through which pass blood-vessels and nerves into the pulp-chamber, which contains *dental pulp*. This latter is composed of a gelatinous connective tissue with branched cells, together with the blood-vessels and nerves just

FIG. 40.—Scheme of a longitudinal section through a human tooth; in the enamel are seen the "lines of Retzius" (Böhm and Davidoff).

mentioned; lymphatic vessels are absent. Some of the cells are in contact with the dentin of the tooth, and having been concerned in its formation are called *dentin-forming cells* or *odontoblasts*.

The solid part of a tooth, excluding the pulp-chamber and its

contents, is made up of *dentin* or *ivory*, *enamel*, and *cement* or *crusta petrosa*.

*Dentin*.—The main portion of a tooth is composed of dentin, which forms the walls of the pulp-chamber. It bears some resemblance to bone, though the Haversian canals and lacunæ, which characterize the latter, are not present; it is, however, regarded as modified bone. Chemically it consists of 10 per cent. water and 90 per cent. solids, of which latter 27.70 per cent. is organic, collagen and elastin, and 72.30 per cent. inorganic. Of this, calcium carbonate and phosphate form 72 per cent., and magnesium phosphate and calcium fluorid the rest.

Microscopically, dentin is made up of *dentinal tubuli*, hollow tubes, which present a wavy appearance, between which is *intertubular tissue*. In general, the tubules are parallel with one

FIG. 41.—Cross-section of human tooth, showing cement and dentin;  $\times 212$  (Böhm and Davidoff). At *a* are seen small interglobular spaces (Tomcs' granular layer).

another, although in the upper part of the crown they are arranged vertically, while in the neck and root they are oblique. They extend from the enamel and cement to the pulp-chamber, into which they open, and from the odontoblasts of which they receive processes; the dentin thus resembling bone in which bone-corpuscles send processes into the canaliculi. At the ends, which open into the pulp-chamber, the tubules are unbranched, but as they extend toward the enamel and cement they divide *dichotomously*—i. e., into two branches, each of which again divides in the same manner. They terminate beneath the enamel and cement in irregular communicating spaces, *interglobular spaces* or the *granular layer*.

The intertubular tissue contains the greater portion of the inorganic constituents of the dentin.



a  
b

u

d  
c

a  
b  
c  
d  
p

FIG. 43.

FIG. 42.

FIG. 44.

FIG. 45.

FIGS. 42-45.—Four stages in the development of a tooth in a sheep embryo (from the lower jaw) (Böhm and Davidoff). FIG. 42, anlage of the enamel-germ connected with the oral epithelium by the enamel-edge; FIG. 43, first trace of the dentinal papilla; FIG. 44, advanced stage with larger papilla and differentiating enamel-pulp; FIG. 45, budding from the enamel-edge of the anlage of the enamel-germ, which later goes to form the enamel of a permanent tooth; at the periphery of the papilla the odontoblasts are beginning to differentiate. FIGS. 42, 43, and 44,  $\times 110$ ; FIG. 45,  $\times 40$ . a, a, a, a, Epithelium of the oral cavity; b, b, b, b, its basal layer; c, c, c, the superficial cells of the enamel-organ; d, d, d, d, enamel-pulp; p, p, p, dentinal papilla; s, s, enamel-forming elements (enamel-cells); o, odontoblasts, S, enamel-germ of the permanent tooth; v, part of the enamel-edge of a temporary tooth; u, surrounding connective tissue.

**Enamel.**—This covers the crown and extends to the root. It is the hardest part of a tooth—indeed, it is the hardest tissue in the human body—and protects the softer and more sensitive portion beneath in the process of mastication or chewing. It is made up of elongated hexagonal prisms, *enamel-prisms*, which are placed at right angles to the dentin (Fig. 46).

Chemical analyses of enamel vary to a considerable extent. Hoppe-Seyler gives the following: Calcium carbonate and phosphate, 96 per cent.; magnesium phosphate, 1 per cent.; and organic substances, 3 per cent. Other chemists state the amount of organic matter to be from 2 to 10 per cent.; but the most recent

Enamel.

Branching of the  
dental tubules.

Dental tubules.

Interglobular  
space.

FIG. 46.—A portion of a ground tooth from man, showing enamel and dentin;  $\times 170$  (Böhm and Davidoff).

analyses seem to show that the organic matter present in the enamel of a fully formed tooth is too minute to be weighed.

**Cement or Crusta Petrosa.**—At the point where the enamel ends the cement begins, and forms a covering of the dentin as far as the tip of the root. It is both structurally and chemically identical with bone, possessing both lacunæ and canaliculi. The presence of Haversian canals is claimed by some histologists, especially in the thicker portions; while others deny it in normal teeth. Like bone, the cement is covered with periosteum, which

lines the alveolus and holds the tooth in its place. It is here called *pericementum*.

*Development of Teeth* (Figs. 42-45).—About the seventh week of fetal life the germinal epithelium which covers the mucous membrane of the gums of the embryo, grows so as to form an elevated ridge, the *maxillary rampart*. A similar growth occurs downward into the tissue of the mucous membrane, forming the *common dental germ* or *dental lamina*. From this lamina ten cellular processes, the *special dental germs*, are given off in each jaw, corresponding to the number of teeth. Each special germ becomes

FIG. 47.—A portion of a cross-section through a developing tooth (later stage than in Fig. 45);  $\times 720$  (Böhm and Davidoff). The dentin is formed, but has become homogeneous from calcification. Bleu de Lyon differentiates it into zones (a and b). At c is seen the intimate relationship of the odontoblasts to the tissue of the dental pulp.

flask-shaped, and later flattened, and still later indented on its under side. The special germ becomes the *enamel-organ* of the future tooth, as from it the enamel is produced. From the corium of the mucous membrane grows a vascular papilla, the *dental papilla*, which, as it grows, increases the indentation of the special germ and is covered by it. This papilla becomes the dentin and pulp of the tooth, the odontoblasts which cover it forming the dentin and the other portion the pulp. From the tissue which produces the papilla a vascular sac, the *dental sac*, is formed, which surrounds the special germ and its papilla. The dental sac and all the structures within it constitute the *dental follicle*.

The epithelial cells of the special dental germ become changed into three kinds of cells: (1) Columnar cells, *adamantoblasts* or *ameloblasts*. These are the deepest layer next the papilla, and therefore next the future dentin. The adamantoblasts form the enamel-prisms (Fig. 46), at first fibrous in character, later becoming calcified. (2) The outer cells, those adjoining the dental sac, become arranged into a single layer of cubical epithelium. Between the two the cells form a spongy network of (3) branching cells, whose processes communicate, forming the *stellate reticulum* or *enamel-jelly* or *enamel-pulp*. The name *enamel-organ* is now applied to this structure.

The cement, which, as already stated, is identical with bone, is formed by the dental sac, whose internal tissue is in all respects the same as the osteogenetic layer of periosteum. The outer layer of this sac is the *dental periosteum*.

The above description is that of the development or formation of the *temporary* or *milk-teeth* (p. 56). The *permanent* teeth are formed in the same manner. The process from which each of these latter is developed is an offshoot of the special dental germ, which produces a temporary tooth, and this offshoot undergoes the same changes. The milk-teeth are shed by the action of the osteoclasts of the dental periosteum, here called *odontoclasts*, which cause absorption of the roots of these teeth.

While there are but ten temporary teeth in each jaw, there are, on the other hand, sixteen permanent ones, or six more; the permanent molars, three on each side of the jaw, the *first* and *second molars*, and the *wisdom-teeth*. These arise from a backward extension of the dental germ, for which additional special germs are developed.

The *eruption* or *cutting* of the teeth is due to the absorption of the gum about them by the pressure of the growing teeth.

The *alveoli* or sockets are formed by the ossification of the tissue between the dental sacs.

The ten teeth which replace the ten temporary are called *successional permanent teeth*; the other six, *superadded permanent teeth*. The molars of the temporary set are replaced by the premolars or bicuspidis of the permanent set, while the superadded teeth are the molars of the permanent set, and have no representatives in the temporary set.

While the formation of the milk-teeth begins at about the seventh week of fetal life, that of the successional permanent teeth commences at about the sixteenth week, the second molars at the third month, and the wisdom teeth at the third year.

*Temporary, Milk-, or Deciduous Teeth.*—The first set of teeth, ten in number in each jaw, twenty in all, constitute the *temporary, milk-, or deciduous teeth*. Four of these are *incisors*, two *canines*, and four *molars*. The following table gives their arrangement and approximate time of eruption or cutting.

TEMPORARY TEETH.

Arrangement and Time of Eruption.

One-half only of each jaw is represented, the arrangement and time of eruption being the same in the corresponding halves.

	Molars.		Canine.	Incisor.		Middle line of jaw.
	Second.	First.		Lateral.	Central.	
Upper jaw . . . . .	1	1	1	1	1	
Time of eruption in months after birth . . . . .	20-24	15-21	16-20	15-21	8-10	
Lower jaw . . . . .	1	1	1	1	1	
Time of eruption in months after birth . . . . .	20-24	12	16-20	15-21	6-9	

*Permanent Teeth.*—The second or permanent set consists of thirty-two teeth, sixteen in each jaw. The third molars or wisdom teeth do not always appear. The following table gives the arrangement of these teeth and the approximate time of their eruption :

PERMANENT TEETH.

Arrangement and Time of Eruption.

One-half only of the jaw is represented, the other half corresponding in all particulars ; and as the time of eruption of the permanent teeth of the lower jaw differs from that of the upper only in that it precedes it slightly, the upper jaw is alone represented.

	Third or Wisdom.	Molar.		Bicuspid or Premolar.		Canine.	Incisor.		Middle line of jaw.
		Second.	First.	Second.	First.		Lateral.	Central.	
Upper jaw . . . . .	1	1	1	1	1	1	1	1	
Time of eruption in years after birth . . . . .	17-25	12	6	10	9	11	8	7	

MUSCULAR TISSUE.

The muscular tissue of the human body is of two kinds, *voluntary* and *involuntary*, both being possessed of *contractility* or the power to shorten.

**Voluntary Muscle** (Fig. 49).—This is composed of fibers having a length of 2.5 cm. or more, and a diameter of 0.05 mm., enclosed in a sheath, the *sarcolemma* (Fig. 48). The material possessed of contractile power, *contractile substance*, when viewed under the microscope presents the appearance of alternating dark and light stripes, *striæ*, crossing it, giving to this variety the name of *striated muscle*. These *striæ* are not superficial markings, but are in reality the edges of dark and light disks (Fig. 49). At the boundaries of the light *striæ* are seen rows of granules, and running through the dark *striæ* lines connecting the granules. These lines mark longitudinally the subdivisions of the muscle, which

are called *muscle-columns*, *sarcostyles*, or *fibrils*. When stained with chlorid of gold transverse lines are also seen uniting the granules, the whole arrangement of lines presenting a reticular appearance,

FIG. 48.—Striated muscle-fiber of frog, showing sarcolemma (Huber).

which, however, Schäfer regards as in reality not a network, but only the optical expression of the interstitial substance between the muscle-columns, and which is called *sarcoplastm*.

If a muscle-fiber is examined in cross-section, it is found to be divided into angular areas, *Cohnheim's areas* (Fig. 51). These are

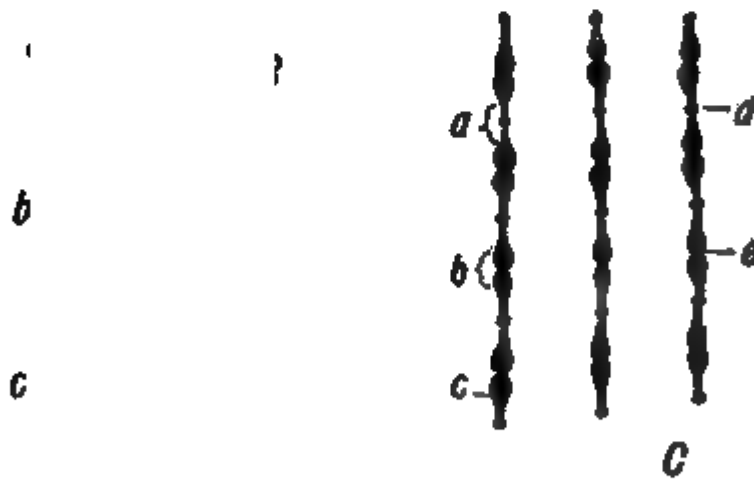


FIG. 49.—Voluntary muscle (Leroy). *A*, Three voluntary fibers in long sections: *a*, three voluntary muscle-fibers; *b*, nuclei of same; *c*, fibrous tissue between the fibers (endomysium); *d*, fibers separated into sarcostyles. *B*, Fiber (diagrammatic): *a*, dark band; *b*, light band; *c*, median line of Hensen; *d*, membrane of Krause; *e*, sarcolemma; *f*, nucleus. *C*: *a*, Light band; *b*, dark band; *c*, contracting elements; *d*, row of dots composing the membrane of Krause; *e*, slight narrowing of contracting element aiding in production of median line of Hensen.

the cross-sections of the muscle-columns or sarcostyles, between which is the sarcoplastm.

*Hensen's line* is a line crossing a muscle-fiber in the middle of

a dark stripe, while Dobie's line crosses each light stripe. This latter is regarded by Schäfer as not an actual structure, but an effect produced by the transmitted light. One authority, Haycroft, regards the striated appearance of muscle as a refractive effect simply; but the evidence of this is not convincing, and the difference in reaction to staining-agents seems to prove that the light and dark stripes of muscle-fibers are different structures.



FIG. 50.—Diagram of the structure of the fibrils of a striated muscle-fiber; the light spaces between the fibrils may represent the sarcoplasm (Huber).

FIG. 51.—Transverse section through striated muscle-fibers of a rabbit (Böhm and Davidoff). 1 and 3, from a muscle of the lower extremity; 2, from a lingual muscle;  $\times 900$ . In 2, Cohnheim's fields are distinct; in 1, less clearly shown; in 3, the muscle-fibrils are more evenly distributed.

*Nuclei* are to be seen under the sarcolemma of the muscular tissue presenting the usual appearance of cell-nuclei, often with spiral chromoplasm.

*Endomysium* is the areolar tissue between the individual fibers, which are bound together by connective tissue, *perimysium*, into bundles, *fasciculi*; these in turn, united by the *perimysium*, constitute what is commonly called a muscle, whose investment or sheath is the *epimysium*.

The muscles of insects are characterized by broad stripes whose

structure is very distinct, and the following description from Schäfer is very instructive. He says:

"The wing-muscles of insects are easily broken up into sarco-styles (fibrils), which also show alternate dark and light striæ.

"The sarco-styles are subdivided at regular intervals by thin transverse disks (membranes of Krause) into successive portions, which may be termed *sarcomeres*. Each sarcomere is occupied by a portion of the dark stria of the whole fiber (*sarcous element*): the sarcous element is really double, and in the stretched fiber separates into two at the line of Hensen. At either end of the sarcous element is a clear interval separating it from the membrane of Krause; this clear interval is more evident the more the sarco-style is extended, but diminishes to complete disappearance in the contracted muscle. The cause of this is to be found in the

Nucleus.

Muscle-  
substance.

Sarcolemma.

FIG. 52.—Cross-section of striated muscle-fibers: 1, of man; 2, of the frog; the relations of the nuclei to the muscle-substance and sarcolemma are clearly visible;  $\times 670$  (Böhm and Davidoff).

structure of the sarcous element. Each sarcous element is pervaded with longitudinal canals or pores, which are open in the direction of Krause's membranes, but closed at the middle of the sarcous element. In the contracted or retracted muscle the clear part of the muscle-substance has passed into these pores, and has therefore disappeared from view, but swells up the sarcous element and shortens the sarcomere in the extended muscle; on the other hand, the clear part has passed out from the pores of the sarcous element, and now lies between this and the membrane of Krause, the sarcomere being thereby lengthened and narrowed. The sarcous element does not lie free in the middle of the sarcomere, but is attached laterally to a fine enclosing envelope, and at either end to Krause's membrane by very fine lines, which may represent fine septa running through the clear substance."

Schäfer regards the sarcomere as similar to the protoplasm of an ameboid cell, the substance of the sarcous element being repre-



sented by the spongioplasm, and the clear substance by the hyaloplasm. When stimulated, the clear substance passes into the pores as the hyaloplasm does into the spongioplasm, thus producing contraction; and in the absence

FIG. 53.—Diagrams of the transverse striation in the muscle of an arthropod; to the right with the objective above; to the left with the objective below its normal focal distance (after Rollet, 85): *Q*, transverse disk; *k*, median disk (Hensen); *E*, terminal disk (Merkel); *N*, accessory disk (Engelmann); *J*, isotropic substance (Böhm and Davidoff).

FIG. 54.—Cardiac muscle, semidiagrammatic: *a*, nucleus; *b*, branch of fibers; *c*, cross-striation.

of stimulation it passes out, as in the case of the ameba, causing in it the formation of pseudopodia, and in the muscle its extension.

Nucleus

Contractile  
substance.

1.

FIG. 55.

Longitudinal and cross-section of muscle-fibers from the human myocardium, hardened in alcohol;  $\times 640$ . The muscle-cells in the longitudinal section are not sharply defined, and appear as polynuclear fibers blending with one another: between them lie, here and there, connective-tissue nuclei (Böhm and Davidoff).

FIG. 56.

He calls attention to the similarity of the movements of the ameba, muscle, and cilia.

Muscles are well supplied with blood-vessels, which run lengthwise of the muscle with transverse branches; they do not penetrate the sarcolemma. The motor nerves of striated muscle terminate in *motor end-organs*, and the sensory nerves in *muscle-spindles*, which are further referred to in the discussion of Nerve-endings (p. 64). Besides the muscle-fibers, muscles contain connective tissue with some fat.

Striated muscle is found in all the muscles of the body which are attached to bone, and is sometimes described under the name *skeletal muscle*. Although this variety is said to be voluntary, it is not in all places under control of the will, as, for instance, in the pharynx, esophagus, and the internal ear.

**Development of Striated Muscular Tissue.**—Embryonic cells of the mesoblast become elongated, and the nuclei form long fibers, which later become striated; some of the nuclei remain beneath the sarcolemma as the nuclei of the muscle.

**Cardiac Muscle (Fig. 54).**—The muscle of which the heart consists differs from that just described in having its striæ less marked, in being without sarcolemma, and in the fact that its fibers are short, each possessing a nucleus, and that they branch and join the fiber-cells contiguous to them.

The nerves supplying cardiac muscle end in plexuses or networks.

**Involuntary Muscle (Fig. 57).**—This is also called *plain* and *non-striated*. It consists of flat, fusiform cells, contractile fiber-cells, having lengths varying considerably, each possessing a nucleus and one or two nucleoli, and having longitudinal striæ. The cells are joined together by means of an intercellular material.

Involuntary muscular tissue is widely disseminated over the body; it is found in the following locations: esophagus, muscular and mucous coats of the alimentary canal, bladder, ureter, uterus, Fallopian tubes, spleen, ciliary muscle, iris, ducts of glands, arte-

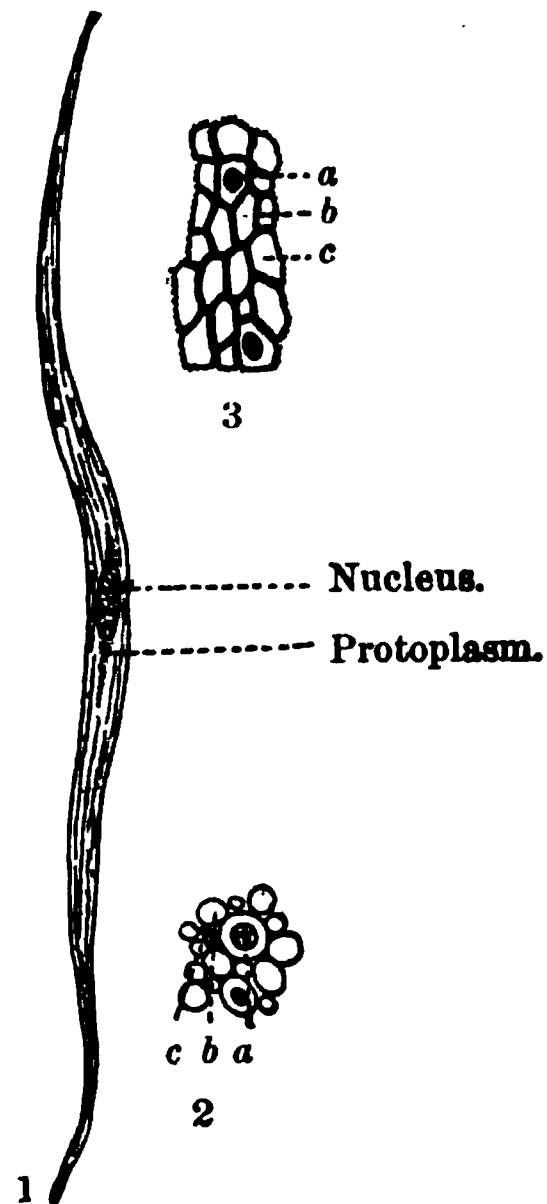


FIG. 57.—Smooth muscle-cells from the intestine of a cat: in 1, isolated; in 2 and 3, in cross-section;  $\times 300$ . At *a* the cell is cut in the plane of the nucleus; at *c*, in the neighborhood of the pointed end. In 3 (from Barfurth) is seen the manner in which neighboring cells are joined to one another by intercellular bridges (Böhm and Davidoff).

ries, veins, lymphatics, sweat-glands connected with hair-follicles, scrotum, and areola of the nipple of the breast.

The nerves of involuntary muscle end in plexuses or networks, as in the cardiac muscle.

**Development of Involuntary Muscular Tissue.**—The contractile fiber-cells which compose this tissue are formed from cells of the mesoblast, which elongate, the nuclei also elongating. The muscular tissue of the sweat-glands is formed from the epiblast. When new muscular tissue of the plain variety is formed, as when the uterus enlarges in pregnancy, growing from an organ weighing from 30 to 40 grams to one weighing from 900 to 1100 grams, this is accomplished by an increase in the size of the original fibers, and by the formation of new fibers from small cells which lie between the original ones. In the process of *involution*, that process by which the uterus returns to its original size, the fibers become fatty and are absorbed.

**Chemical Composition of Striated Muscular Tissue.**—The sarcolemma resembles elastin. When the contractile substance is pressed, a fluid is expressed, the *muscle-plasma*, which coagulates, the clot being *myosin*. A similar change takes place after death, producing *rigor mortis* or *cadaveric rigidity*. During life muscular tissue has an alkaline reaction; while after death, owing partially, at least, to the formation of sarcolactic acid, it becomes acid. This also occurs after the muscles have been very active.

#### PERCENTAGE COMPOSITION OF HUMAN MUSCLES.

Water . . . . .	78.5
Proteids, including the sarcolemma, proteids of connective tissue, vessels, and pigments . . . . .	18.02
Gelatin . . . . .	1.99
Fat . . . . .	2.27
Extractives . . . . .	0.22
Inorganic salts . . . . .	3.12

The proteids in muscle-plasma are three in number: 1. *Paramyosinogen*, which coagulates at 47°–50° C., constituting 17 to 22 per cent. of the total proteid; 2. *Myosinogen* or *Myogen*, coagulating at 56° C., 77 to 83 per cent.; and traces of an albumin, *Myo-albumin*. Both paramyosinogen and myosinogen enter into the clot which forms when the plasma coagulates. This clot is called *myogen-fibrin* or *myosin-fibrin*.

The extractives are very numerous, creatin, creatinin, xanthin, hypoxanthin, carnin, carnic acid, uric acid, tannin, and inosinic acid, all containing nitrogen and fats, glycogen, inosit, dextrose, and sarcolactic acid. This acid is attributed by some authorities to the glycogen, while others trace it to the proteids. The presence of urea in mammalian muscular tissue is still a matter of dispute. Muscular tissue always contains fat, and there is excellent authority for believing that, while some of this comes

from the adipose tissue which cannot be separated from the true muscular tissue, fat is also a constituent part of muscle-plasma.

The coloring-matter of the red muscle is *myohematin*, which is probably produced from the hemoglobin of the blood.

The inorganic salts are principally those of potassium, the most abundant being potassium phosphate.

*Composition of the Cardiac Muscle.*—This variety of muscular tissue contains paramyosinogen and myosinogen, and undergoes cadaveric rigidity.

*Composition of Involuntary Muscular Tissue.*—Cadaveric rigidity has been observed in the stomach and uterus; and from plain muscular tissue a proteid has been obtained which resembles myosinogen.

### NERVOUS TISSUE.

The nervous tissue of the body is made up of nerve-fibers, nerve-cells, and neuroglia.

**Nerve-fibers** (Fig. 58).—This kind of nervous tissue is also called *fibrous* and *white nervous matter*. Fibrous nervous matter should not be confounded with fibrous connective tissue; the term “fibrous” simply implies that the nervous substance is arranged in fibers.

Nerve-fibers are *medullated* and *non-medullated*.

**Medullated Nerve-fibers** (Fig. 58) are

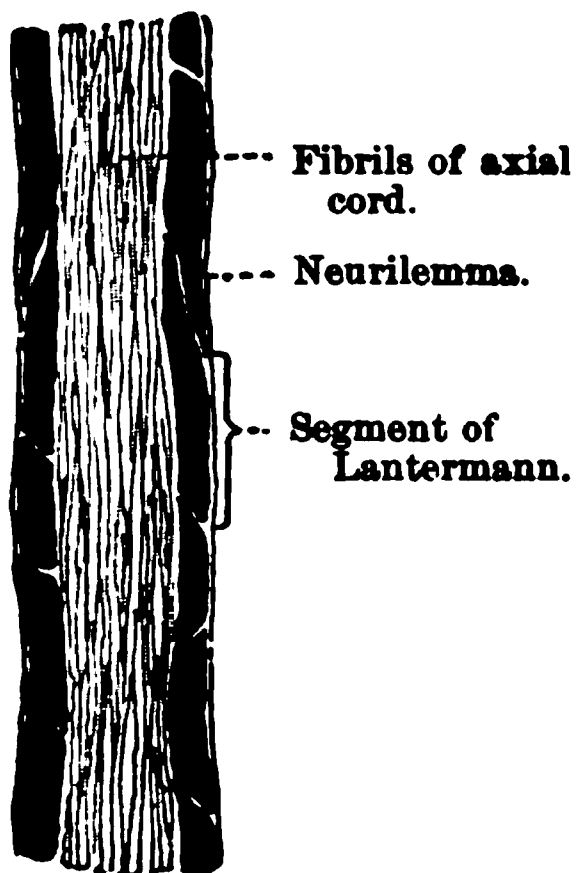


FIG. 58.

FIG. 58.—Longitudinal section through a nerve-fiber from the sciatic nerve of a frog;  $\times 830$  (Böhm and Davidoff).

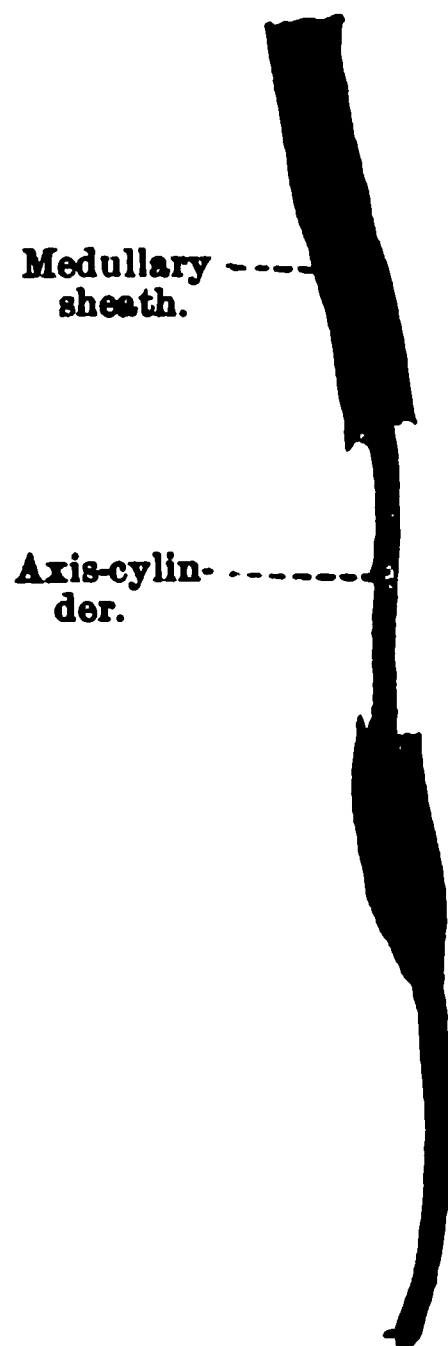


FIG. 59.

FIG. 59.—Medullate nerve-fiber from sciatic nerve of a frog; in two places the medullary sheath has been pulled away by teasing, showing the “naked axis-cylinder”;  $\times 212$  (Böhm and Davidoff).

characterized by possessing a *medullary sheath* or *white substance of Schwann*, which gives the white color to the nerve-fiber. This is a protective covering to the essential part of a nerve, the *axis-cylinder*. The space inside the medullary sheath is the *axial space*, which is filled by the *axial cord*. This consists of *axis-fibrils* embedded in the *neuroplasm*, a material of semi-fluid consistency, both fibrils and neuroplasm being covered by a delicate membrane, the *axolemma*. When nerve-fibers have been prepared for microscopic examination the axial cord changes its appearance by the coagulation of the neuroplasm, and the altered cord is what is commonly called the *axis-cylinder*. The *primitive sheath*, *nucleated sheath of Schwann*, or *neurilemma*, is a membrane which encloses

the white substance of the nerves, excepting those within the nerve-center. Neurilemma (also written neurolemma) is a term formerly applied to what is now called *perineurium*.

The medullary sheath is not continuous; at regular intervals it is absent, and only the primitive sheath and axis-cylinder are present. This gives to the nerve the appearance of *constrictions*, known also as the *nodes of Ranvier*. The portion of nerve between these constrictions is an *internode*, in the middle of which is a nucleus.

Medullated fibers make up the white part of the brain and spinal cord, and the nerves that have their origin in these structures, the *cerebrospinal* nerves. In size they vary from  $2\ \mu$  to  $19\ \mu$ . This variety never branches except near the termination.

FIG. 60.—Remak's fibers (nonmedullated fibers) from the pneumogastric nerve of a rabbit;  $\times 360$  (Böhm and Davidoff).



**Nonmedullated Nerve-fibers** (Fig. 60).—These are also known as *gray*, *gelatinous*, and *fibers of Remak*. These have no white substance, but are composed of fibrillæ, which are probably enclosed in a sheath, the neurilemma, in which are nuclei.

Nonmedullated fibers, unlike those that are medullated, frequently branch.

Nerve-fibers are associated together in bundles, *funiculi* (Fig. 61), each of which bundles is enclosed in a sheath of connective tissue, *perineurium*. The funiculi are surrounded by a similar sheath, the *epineurium*, which binds them together and in which are the blood-vessels, lymphatics, and nerves of the nerves, the last being the *nervi nervorum*. Within the funiculi is connective tissue, embedded in which are the nerve-fibers.

**Modes of Termination of Nerve-fibers.**—The nerves which supply striated muscle subdivide near their ends, and one of the

branches goes to a muscular fiber. Its primitive sheath is continuous with the sarcolemma, and the medullary sheath terminates. The axis-cylinder breaks up into fine ramifications, which are embedded in granular nucleated protoplasm; this is a *motor end-organ* or *end-plate* (Figs. 62-65).

In involuntary muscle the nerve-fibers end in plexuses, from which fine branches pass to the contractile fiber-cells.

Nerve-fibers also end in *special organs*, of which there are various kinds: *End-bulbs of Krause*, *tactile corpuscles*, *Pacinian corpuscles*, *organs of Golgi*, and *muscle-spindles*.

*End-bulbs* (Fig. 67).—An end-bulb consists of a cylindrical, oblong, or spheroidal body formed from the connective-tissue sheath of a medullated nerve-fiber. Within this is a core with many nucleated cells, in which the axis-cylinder terminates. End-

Connective  
tissue.

Fibrils of axial  
cord.

Medullary  
sheath.

Fibrils.

a  
b

FIG. 61.—Transverse section through the sciatic nerve of a frog;  $\times 820$ ; at *a* and *b* is a diagonal fissure between two Lantermann segments; as a result, the medullary sheath here appears double (Böhm and Davidoff). (Compare Fig. 60.)

bulbs are found in the conjunctiva, in the papillæ of the lips and tongue, the skin and mucous membrane of the penis, the clitoris, vagina, epineurium of nerve-trunks, and in tendon.

In the synovial membrane of some joints, as in the fingers, end-bulbs also occur, and are here called *articular end-bulbs*.

*Tactile Corpuscles*.—These consist of connective tissue which forms a capsule, from which are given off membranous partitions or septa. After winding around the corpuscle the axis-cylinder enters it, and terminates in an enlargement. Tactile corpuscles occur in the papillæ of the skin of the hand, foot, front of the forearm, lips, and nipple; also in the mucous membrane of the tip of the tongue and the conjunctiva lining the eyelids.

*Pacinian Corpuscles* (Fig. 70).—These are also called *corpuscles of Vater*. Each corpuscle consists of concentrically arranged layers of connective tissue, with nucleated cells. A medullary

Nerve  
end-  
brush.  
So-called  
granular  
sole.

Nerve.  
Nerve.

Muscle-  
fiber.

So-called  
granular  
sole.

Nerve  
end-  
brush.  
Muscle-  
fiber.

Nerve.

FIG. 62.

FIG. 63.

So-called  
granular  
sole.  
End-brush.

Muscle-  
fiber. Sarc-  
lemma.

FIGS. 64 and 65.

FIG. 66.

FIGS. 62-65.—Motor endings in striated voluntary muscles.

FIG. 62, from *Pseudopus Pallasi*;  $\times 160$ . FIG. 63, from *Lacerta viridis*;  $\times 160$ . FIGS. 64 and 65, from a guinea-pig;  $\times 700$ . FIG. 66, from a hedgehog;  $\times 1200$ . As a consequence of the treatment (T. 182, I) the arborescence is shrunken and interrupted in its continuity. In FIGS. 62 and 63 the end-plate is considerably larger than in FIGS. 64 and 65. In FIG. 62 it is in connection with two nerve-branches. FIG. 66 shows a section through an end-plate. The latter is bounded externally by a sharply defined line, which can be traced along the surface of the muscle-fiber. This is to be regarded as the sarcolemma (Böhm and Davidoff).

nerve-fiber enters at one end and passes into an interior space which contains a transparent substance; here only the axis-

FIG. 67.—End-bulb of Krause from conjunctiva of man; methylene-blue stain (Dogiel).

FIG. 68.—Cylindric end-bulb of Krause from intermuscular fibrous tissue septum of cat; methylene-blue stain (Huber).

cylinder is present. This terminates at the end of the corpuscles in an enlargement or in minute branches, an *arborization*.

These corpuscles exist in the subcutaneous tissue of the palm

Nucleus of lamellæ.

End-cell of core.

Lamellæ.

Axis-cylinder in core.

Cubic cells of core.

Termination of medullary sheath.

Axis-cylinder of nerve-fiber.

Medullary sheath of nerve-fiber.

Neurilemma and sheath of Henle.

FIG. 69.—Corpuscle of Herbst from bill of duck;  $\times 600$  (Böhm and Davidoff).

of the hand and sole of the foot, and in the penis. Observers have also found them in the pancreas, lymphatic glands, and thyroid.



FIG. 70.—Pacinian corpuscles from mesorectum of kitten: *A*, showing the fine branches on central nerve-fiber; *B*, the network of fine nerve-fibers about the central fiber; methylene-blue preparation (Sala).

FIG. 71.—Genital corpuscle from the glans penis of man; methylene-blue stain (Dogiel).

FIG. 72.—Meissner's tactile corpuscle; methylene-blue stain (Dogiel).

**Organ of Golgi (Fig. 73).**—At the point where muscles and their tendons join, the tendon-bundles present an enlargement, between the fasciculi of which one, two, or more nerve-fibers enter to terminate in an arborization which is characterized by varicosities. The term "organ of Golgi" includes the enlargement and the arborizations.

**Muscle-spindles.**—These are described under the name neuro-muscular spindles. A spindle is a fusiform body having a length of from 0.75 mm. to 4 mm. Externally is a sheath of connective tissue within which is the *interposed bundle*, consisting of from ten to twelve muscle-fibers, resembling embryonic fibers. The nerve-fibers distributed to these spindles divide, and the axis-cylinders clasp the fibers by flattened expansion. None of these spindles has been found in either the muscles of the eye or the tongue. They are considered to be sensory nerve-endings in the muscles.

**Nerve-cells (Figs. 75-78).**—This kind of nervous tissue is also called *gray, cineritious, cellular, vesicular, nervous matter*.

Nerve-cells are of different sizes, varying from  $4\ \mu$  to  $150\ \mu$ . Their shape also varies greatly, some being ovoid, while others are very irregular in outline. Each cell contains a large, distinct, and spheroidal nucleus, with a single nucleolus, and fibrillated protoplasm. In the protoplasm are sometimes angular granules, *Nissl's granules*, which are stained by methylene-blue.

From nerve-cells are given off two kinds of processes: axis-cylinder processes or *neuraxes*, and protoplasmic processes or *dendrites*. These are the principal elements in nerve-fibers. The number of these processes or

FIG. 73.—Neurotendinous nerve end-organ from rabbit; teased preparation of tissue stained in methylene-blue (Huber and De Witt, *Jour. of Comp. Neurol.*, vol. x.).

*poles* determines the name of the cell: thus a cell with one pole

FIG. 74.—Cross-section of neurotendinous nerve end-organ of rabbit, from tissue stained in methylene-blue: *m*, muscle-fibers; *t*, tendon; *c*, capsule of neurotendinous end-organ; *m n*, medullated nerve-fiber (Huber and DeWitt, *Jour. of Comp. Neurol.*, vol. X.).

is *unipolar*; one with two poles, *bipolar*; and one with three or more, *multipolar*.

Nucleus.

Nucleolus.

Fibrillar structure.

Medullary sheath.

FIG. 75.—Bipolar ganglion-cell from the ganglion acusticum of a teleost (longitudinal section); the medullary sheath of the neuraxis and dendrite is continued over the ganglion-cell;  $\times 800$  (Böhm and Davidoff).

The process in a so-called “unipolar” cell is, in reality, two processes which have become united. Such cells occur in the spinal ganglia (Fig. 78).

**Axis-cylinder Process.**—Every nerve-cell has an axis-cylinder process, which, in the medullated nerve-fiber, becomes the axis-cylinder, and in the non-medullated is the nerve-fiber itself. This

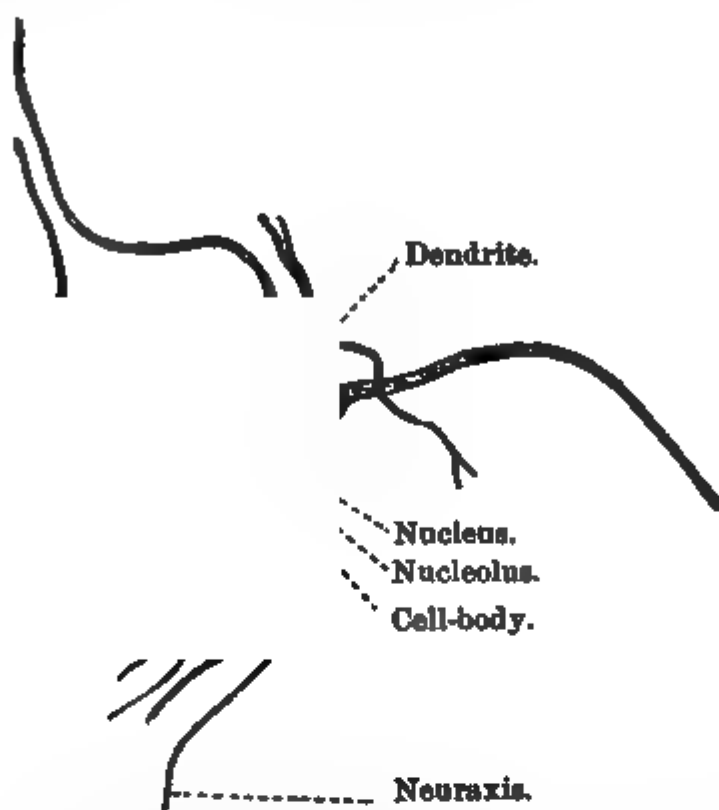


FIG. 76.—A ganglion-cell from anterior horn of the spinal cord of calf; teased preparation;  $\times 140$ ; by this method only the coarsest ramifications of the dendrites are preserved; the rest are torn off (Böhm and Davidoff).

process is characterized by the fact that it gives off a few side-shoots, *collaterals* in its course; thus its branching is very limited. To this process some histologists apply the term *neuron*,

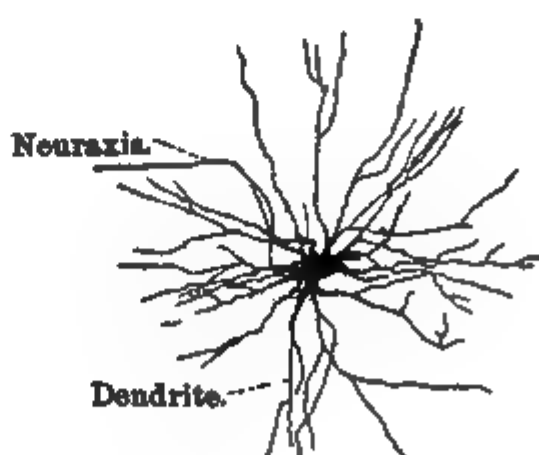


FIG. 77.—Motor neurones from the anterior horn of the spinal cord of a newborn cat; chrome-silver method (Huber).

while others call it *neuraxon*, or *axon*, and reserve the term "*neuron*" for the whole nerve-unit—that is, the cell and all its processes, for which the term *neurone* is more commonly used.

Cells which have but one axis-cylinder process are *mononeuric*; those having two such processes are *dineuric*; and *trineuric* is applied to those having three. Most nerve-cells are mononeuric.

**Ganglia.**—A ganglion is a collection or group of nerve-cells. These occur upon the posterior roots of the spinal nerves (Fig. 78), upon some of the cranial nerves, and in connection with the sympathetic nervous system. In these structures the cells have a nucleated sheath continuous with that of the nerve-fibers connected with them. From each cell in the ganglion, upon the roots of the spinal cord, and among the cranial nerves is given off but one process, the axis-cylinder process. Passing in a convoluted form from the cell, this process, before it leaves the ganglion, divides into two, one going to the nerve-center, the other to the

periphery. From this description it will be seen that these cells have no dendrons.

In the cells of the sympathetic ganglion, besides the axis-cylinder process, there are also several dendrons.

**Protoplasmic Process.**—Unlike the axis-cylinder process, this variety is characterized by its frequent branching. The larger branches are called *dendrons*, and the finer ones *dendrites*.

The idea that the axis-cylinder process alone conveys nervous impulses, and that the den-

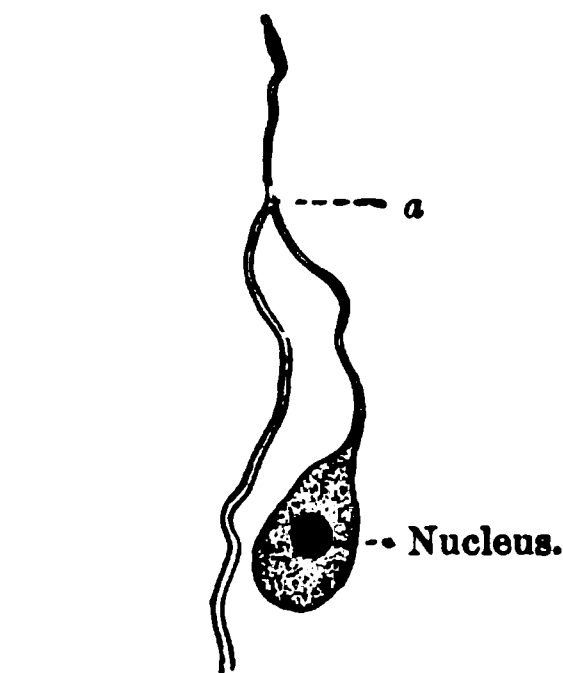


FIG. 78.—Ganglion-cell with a process dividing at *a* (T-shaped process); from a spinal ganglion of the frog;  $\times 230$  (Böhm and Davidoff).

drons and dendrites are nutritive organs exclusively, is at the present time replaced by the belief that nervous impulses also travel along the branches of the protoplasmic process. The anatomic fact that the fibrils of the axis-cylinder have been traced through the body of the cell into the dendrons, seems to substantiate this theory.

It is a most important fact that the nerve-unit, or the "*neurone*" of some writers—that is, the nerve-cell and its branches—does not anastomose or join with any other nerve-unit, but the terminal twigs or *arborizations* of one intertwine with those of another, and nerve-impulses may thus pass from one to the other. This intertwining is called *synapse*, a word literally meaning a clasping. This subject will be again referred to when the physiology of nerves is discussed.

**Neuroglia** (Fig. 79).—This is sometimes spoken of as a connective tissue, but it is in structure unlike connective tissue as we have studied it. It is also unlike it chemically, consisting of

neurokeratin. Its origin from the epiblast also differentiates it from connective tissue, which arises from the mesoblast.

Neuroglia is the supporting tissue of the nerve-cells and nerve-fibers of the brain and spinal cord. It consists of cells and fibers. In describing ciliated epithelium it will be remembered that among the locations in which it was found the ventricles of the brain and the central canal of the spinal cord were mentioned. From the attached ends of these cells branching neuroglia-fibers pass to the surface of the brain and the cord, and terminate at the pia mater in enlargements. Other fibers of the neuroglia arise from cells, *neuroglia*, *glia*- or *spider-cells*, which are stellate in shape. These fibers aid in supporting the nerve-cells and nerve-fibers.

**Development of Nerve-cells and Nerve-fibers.**—The following description is from Schäfer: "All nerve-cells in the body are developed from the cells of the neural groove and neural crest of the early embryo; the neural groove closing to form the neural canal, the cells of which form the spinal cord and brain, and the neural crest giving off, at intervals, sprouts which become the rudiments of the ganglia. The cells which line the neural canal are at first all long, columnar cells, but among these, and probably produced by a metamorphosis of some of these, rounded cells (*neuroblasts*) make their appearance, and presently from each one a process begins to grow out. This is the axis-cylinder process (*neuron*) and is characterized by its enlarged extremity. As it grows, it may emerge from the anterolateral regions of the canal and become a *motor neuron* or *anterior root-fiber*. The dendrons appear somewhat later than the neuron. The axis-cylinder processes of some of the neuroblasts remain within the nerve-centers, and are developed into association or intracental fibers.

"The sprouts from the neural crest contain the neuroblasts from which the posterior root-fibers are developed. Neurons grow out from

these neuroblasts in two directions, so that the cells become bipolar, one set, forming the posterior root-fibers, grow into the posterolateral portion of the spinal cord, and ramify in the developing gray matter; the other set, containing the afferent fibers of the

FIG. 79.—Neuroglial cells: *a*, from spinal cord of embryo of cat; *b*, from brain of adult cat; stained in chrome silver (Huber).

mixed nerves, grow toward the developing anterior roots, and eventually mingle with them to form the mixed nerves. As development proceeds, the bipolar ganglion-cells become gradually transformed in most vertebrates by the shifting of the two neurons, into unipolar cells; but in many fibers the cells remain permanently bipolar.

“The ganglia on the sympathetic and on other peripheral nerves are formed from small masses of neuroblast-cells, which separate off from the rudiments of the spinal ganglia and give origin to neurons and dendrons much in the same way as do the neuroblasts within the central nervous system.

“The manner in which the medullary sheath and neurolemma of the nerve-fibers are formed is not well understood. The neuroglia-cells appear to be developed from cells which are at first similar to the neuroblasts, but, in place of giving off a neuron and dendrons, a number of fine processes grow out from the cell in all directions, forming the fibers of the neuroglia.”

**Chemistry of Nervous Tissue.**—The following is the analysis of the brain of an ox by Petrowsky :

	Gray Matter.	White Matter.
Water . . . . .	81.60 per cent.	68.80 per cent.
Solids . . . . .	18.40 “ “	81.70 “ “
	100.00	100.00

The percentage composition of the solids is as follows :

	Gray Matter.	White Matter.
Proteids . . . . .	55.87	24.72
Lecithin . . . . .	17.24	9.90
Cholesterin and fat . . . . .	18.68	51.91
Cerebrins . . . . .	0.58	9.55
Other organic compounds (including neurokera- tin and protagon) . . . . .	6.71	3.84
Salts . . . . .	1.45	0.57

Halliburton divides the solid constituents of the nervous tissues into the following classes :

- a. Proteids.—These comprise a very considerable percentage of the solids, especially in the gray matter (over 50 per cent.).
- b. Neurokeratin and nuclein.
- c. Phosphorized constituents, especially protagon and lecithin.
- d. Cerebrins.—Nitrogenous substances of unknown constitution.
- e. Cholesterin.—Especially abundant in white matter.
- f. Extractives.—Creatin, xanthin, hypoxanthin, inosit, lactic acid, leucin, uric acid, and urea.
- g. Gelatin and Fat.—From the adherent connective tissue.
- h. Inorganic Salts.—The total mineral matter varies, according to different writers, from 0.1 to 1 per cent.

Geoghegan gives the following as representing parts per 1000 of brain :

Total ash . . . . .	2.9 to 7.1	Chlorin . . . . .	0.4 to 1.2
Potassium . . . . .	0.6 " 1.7	PO <sub>4</sub> . . . . .	0.9 " 2.0
Sodium . . . . .	0.4 " 1.1	CO <sub>3</sub> . . . . .	0.2 " 0.7
Magnesium . . . . .	0.0 " 0.07	SO <sub>4</sub> . . . . .	0.1 " 0.2
Calcium . . . . .	0.005 " 0.02	Fe(PO <sub>4</sub> ) <sub>3</sub> . . . . .	0.01 " 0.09

Halliburton gives the following table, which shows the proportion of water, solids, and proteids in different portions of the nervous system. The table represents mean analyses of the organs of adult human beings, dogs, cats, and monkeys :

	Water.	Solids.	Percentage of proteids in solids.
Gray matter of cerebrum . . . . .	88.467	16.588	51
White " " . . . . .	69.912	30.088	88
Cerebellum . . . . .	79.809	20.191	42
Spinal cord as a whole . . . . .	71.641	28.854	81
Cervical cord . . . . .	72.529	27.471	81
Dorsal " . . . . .	69.755	30.245	28
Lumbar " . . . . .	72.639	27.631	83
Sciatic nerves . . . . .	61.816	38.684	29

The percentage of neurokeratin is in gray matter 0.3 ; in white matter, 2.2 to 2.9 ; and in nerve, 0.3 to 0.6.

**Proteids of Nervous Tissue.**—The proteids are : 1. A globulin, coagulated by heat at 47° C., analogous to the cell-globulin derivable from cellular tissues generally ; 2. Nucleoproteid, which coagulates at 56°–60° C. and contains 0.5 per cent. of phosphorus ; and 3. A globulin coagulating at 70°–75° C., analogous to a globulin obtained from the liver.

**Protagon.**—It was for some time undecided whether this substance, which was separated from the brain by Liebreich, was a definite substance or a mechanical mixture of lecithin and cerebrin ; but the evidence now at hand seems conclusive in favor of its definiteness of chemic composition. Its percentage composition, as given by Gamgee and Blankenhorn is C, 66.39 ; H, 10.69 ; N, 2.39 ; P, 1.068 ; and O, 19.462. The empirical formula is C<sub>160</sub>H<sub>308</sub>N<sub>5</sub>PO<sub>35</sub>. It is probable that there are more than one protagon.

**Cerebrin.**—This constituent of nervous tissue should be spoken of as cerebrins, as there are more than one. The constitution of them is not known. They contain nitrogen and yield galactose on hydration. They are also called *cerebrosides*, and are constituents of the medullary sheaths, and are also found in the yolk of egg, pus-corpuscles, and spleen-cells.



## II. PHYSIOLOGIC CHEMISTRY.

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PHYSIOLOGIC chemistry, as applied to the human body, may be defined as *the science which treats of the ingredients of the human body and of the human food*. These ingredients are spoken of by some writers as “proximate principles,” by others as the “chemical basis,” and by still others as “physiologic ingredients.” The latter term is the one which will be adopted, as it is the most expressive.

If the human body is analyzed into its ultimate chemical elements, it will be found that of the *sixty-nine* elements known to chemists no less than *fifteen* are constantly present. These elements are oxygen, carbon, hydrogen, nitrogen, calcium, sodium, potassium, iron, phosphorus, sulphur, magnesium, chlorine, fluorine, silicon, and iodine. Some authorities place lithium also in this list. As fluorine and silicon occur in such small proportions, they may be omitted from consideration altogether.

To obtain most of these substances in their elementary form such processes must be adopted as will utterly destroy the tissues. In the body, in its living state, most of these substances do not exist in their elementary condition; and, however interesting it may be to know all the facts about them, still a knowledge of the properties of these elements does not help to an understanding of their offices in the human body. What is really desired to be known is, *under what forms* these elements exist in the body during life, and not what can be obtained by the analytic chemist.

Chemical elements and physiologic ingredients are not interchangeable terms. A physiologic ingredient may be defined as *a substance which exists in the body under its own form*. To determine, then, whether a given substance is or is not a physiologic ingredient of the human body, it must be ascertained whether it does or does not exist there under its own form. For instance, if it is asked if carbon is a physiologic ingredient, before the question could be answered we should have to determine whether carbon exists in the body under its own form—that is, as *carbon*.

Chemistry demonstrates that carbon, as an element, is found in nature in but three forms, namely, as coal, as the diamond, and as graphite or plumbago. In the human body none of these substances is found; therefore carbon does not exist under its own form, and consequently is not a physiologic ingredient, although

more than one-eighth of the body is made up of carbon, and this amount can be obtained from it. But this carbon does not exist under its own form—that is, free or uncombined—but it is all in a state of combination, as carbonates or in carbohydrates or other forms of combination, and when we obtain the carbon as an element these combinations are broken up and the carbon is set free. Water is a physiologic ingredient, because it exists in the body under its own form, and can be obtained therefrom without the use of such violent means as are necessary to destroy chemical combinations.

It is exceedingly important to have a clear conception of what are and what are not physiologic ingredients: all that can be learned of them and their properties will be of assistance; but a knowledge of the properties of their chemical elements will be of no special aid in our physiologic studies, for the properties of a compound are not the sum of the properties of its component parts. One might be thoroughly conversant with the properties of oxygen and hydrogen, and yet have no possible conception of the properties of water, which their combination forms.

**Classification of Physiologic Ingredients.**—The physiologic ingredients of the human body may be classified as follows: Inorganic; Carbohydrates; Fats; Proteids; Albuminoids; Enzymes. Other ingredients will be discussed in connection with the solids or liquids in which they occur.

INORGANIC INGREDIENTS.

Water.

Salts . . . . .	{	Sodium . . . . .	{ Chlorid. Phosphate. Biphosphate. Sulphate. Carbonate. Bicarbonate.
		Potassium . . . . .	{ Chlorid. Phosphate. Sulphate. Carbonate.
		Calcium . . . . .	{ Phosphate. Carbonate. Fluorid.
		Magnesium . . . . .	{ Phosphate. Carbonate.
		Ammonium . . . . .	Chlorid.

Iron } not free.  
 Silicon }  
 Iodin.  
 Oxygen.  
 Hydrogen.  
 Nitrogen.  
 Marsh-gas.  
 Ammonia.  
 Sulphuretted Hydrogen.  
 Hydrochloric Acid.  
 Carbon Dioxid.

**Water (H<sub>2</sub>O).**—Water is one of the most important of the physiologic ingredients. Its quantity in the human body is variously stated by different authorities: Halliburton placing it at 58.5 per cent. of the body-weight of an adult, and 66.4 per cent. of that of infants, while others give it as 68 per cent. It is found in all the tissues, both solid and fluid.

**Quantity of Water in the Body.**—The percentage of water in some of the solids and fluids of the body is as follows:

Enamel of teeth . . . . .	0.2
Dentin . . . . .	10.
Bones (undried) . . . . .	50.
Costal cartilage . . . . .	67.66
Corpuscles of venous blood . . . . .	68.16
Muscles . . . . .	73.
Human milk . . . . .	87.
Plasma of venous blood . . . . .	90.15
Urine . . . . .	93.
Gastric juice . . . . .	98.
Perspiration . . . . .	98.
Saliva . . . . .	99.
Pulmonary vapor . . . . .	99.

From this table it will be seen that while water makes up but a small part of the enamel of the teeth, it constitutes almost the whole of the saliva. Between these two extremes it is present in different tissues in varying proportions. It should be said of these, and of most other quantities given in physiologic tables, that they are not invariable, hence the analyses of different authorities will vary. The composition of the milk, for instance, is not always the same; therefore there will not invariably be 87 per cent. of water present; but the normal variations from this figure, either above or below, will not be very great, and the percentages given in the above table may be regarded as averages.

**Offices of Water.**—We should naturally infer from the large quantity of water present in the body, and from its universal presence in all the solids and liquids, that its offices must be important; and a study of these demonstrates that this is a fact. It is the water which gives to *fluids* their fluidity. Without this property the blood could not circulate through the blood-vessels,

nor dissolve and hold in solution the nutritive materials which it supplies to the tissues, nor carry the waste materials to the various organs whose duty it is to eliminate them. Without water the saliva would cease to be the important agent it is in softening the food in the mouth preparatory to its being swallowed. In short, without water as an integral part of the fluids of the body these fluids would cease to be fluids, and the many and varied offices which they subserve would at once be abolished, and life could no longer be maintained.

Equally important, though less apparent, are the various offices which are subserved by water in the *solids* of the body. From the above table it is seen that water exists in the muscles to the amount of 73 per cent. The striking property of muscles is their power of contractility, or ability to shorten. By the exercise of this property all the movements of the different parts of the body are accomplished: without this power locomotion would be impossible, the movements of the heart would cease, and death would quickly supervene. A muscle deprived of its water would cease to possess this contractile power—in other words, would lose its characteristic function. It must not be inferred from this, however, that it is to the water that muscles owe their contractility, but simply that its presence is one of the conditions essential to the exercise of this power. As will be seen later, the skin possesses most important functions—those, for instance, of sensation, of excretion, and of protection. All these functions would be destroyed if the water in the skin was expelled. Perhaps this fact is nowhere more strikingly evident than in studying the functions of the skin of the palm of the hand. The pliability of this portion of the skin, by which objects are grasped, and the sense of touch, by which it can be determined whether they are hard or soft, whether rough or smooth, whether hot or cold, are both dependent on the presence of water in the skin, and the mere evaporation of the water would at once make the skin hard and rigid, its pliability would vanish, and its functions would cease.

**Sources of Water.**—The water which exists in the body is derived from two principal sources: First, from the food, and second, from its formation in the interior of the body, the former being the main source of supply. As water is a constituent part of every tissue of the human body, so it is of all the varieties of food, both solid and liquid, taken into the body.

The quantity of water in food (percentage) is as follows:

Wheat bread (fresh) . . . . .	83
Mackerel . . . . .	70
Lean beef . . . . .	70
Potato . . . . .	76
Human milk . . . . .	87
Cows' milk . . . . .	87
Green vegetables . . . . .	88

From this table it will be seen that the greater part of potato and of green vegetables is water, and that even of bread, water constitutes a third. In other words, three of every four pounds of potatoes and one of every three pounds of bread are water. In some vegetables, such as the turnip, about 90 per cent. is water. In liquid food, as milk, tea, and coffee, the proportion of water is, of course, still greater. The amount of water daily taken into the body in solid and liquid food aggregates 2000 c.c. In addition to this there is a small amount actually formed within the body.

One of the important ingredients of food is the class of carbohydrates. A study of their composition shows that hydrogen and oxygen exist in these substances in such proportion as to form water. In the various changes which these elements undergo in the body water is formed. Besides this source there is reason to believe that a small quantity of water is formed by the action of free oxygen on some organic substances. The amount of water daily formed in these two ways is not far from 500 c.c., which makes, with the water taken in with the food, a total of 2500 c.c.

**Avenues of Discharge from the Body.**—The water which has been shown to form so essential a part of the body is not, however, a permanent ingredient—that is, while water is always present, it is not the same water : that which at one time exists in the tissues is soon replaced by other water. The amount daily discharged is equal to the amount taken in with the food and formed in the body—that is, about 2500 c.c. The avenues by which it passes out, and the proportion by each, are as follows :

Large intestine, as feces . . . . .	4 per cent.
Lungs, as watery vapor . . . . .	20 “
Skin, as perspiration . . . . .	30 “
Kidneys, as urine . . . . .	46 “

When discharged it is not pure water, but contains ingredients that vary according to the channel by which it is eliminated. The composition of these ingredients respectively will be studied in the appropriate places.

**Salts.**—**Sodium chlorid** or common salt (NaCl) is present in all the solids and fluids of the body, except in the enamel of the teeth. The *quantity* (percentage) in different solids and fluids is as follows :

Milk . . . . .	0.03
Saliva . . . . .	0.15
Gastric juice . . . . .	0.17
Perspiration . . . . .	0.22
Blood . . . . .	0.33
Urine . . . . .	0.55
Bones . . . . .	0.70

The total quantity of common salt in the human body is 110 grams.

*Offices of Sodium Chlorid.*—The most important office which

sodium chlorid subserves is in connection with the process known as "osmosis," or the diffusion of liquids through animal membranes, a subject which will be discussed in connection with the process of absorption. A second office which it possesses is to hold in solution the globulins. The globulins are proteids which are not soluble in distilled water, as are the native albumins, but are soluble in dilute solutions of sodium chlorid (1 per cent.). The so-called "normal" or "physiologic" salt-solution is made by dissolving 6 grams of sodium chlorid in a liter of water. The importance of this office of common salt will be more fully appreciated in the study of the plasma of the blood, of which the globulins form an essential part. A third office which is attributable to it is to aid in the excretion of waste matter. The sodium chlorid of the blood is the source of the hydrochloric acid of the gastric juice.

*Source of Sodium Chlorid.*—The food taken into the body is the principal source of the sodium chlorid which the body contains.

*The quantity (percentage) of this salt in some articles of food is as follows :*

Oats . . . . .	0.01
Turnip . . . . .	0.08
Potato . . . . .	0.04
Cabbage . . . . .	0.04
Beet . . . . .	0.06

It has been the opinion of physiologists that sodium chlorid is not present in sufficient amount in human food to satisfy the demands of the body; consequently, that an additional amount must be taken in as a condiment at the table or be added to the food during the process of cooking. But Dr. F. A. Cook, surgeon to the first Peary North-Greenland Expedition, states that the Eskimos who dwell between the seventy-sixth and seventy-ninth parallels use no salt or condiment of any kind in their food, which is entirely of meat and blubber only one-third cooked. This cooking is done in order that there may be obtained the blood of the meat, and this blood the Eskimos drink. However this may be with the Eskimos, it is the general experience that by the addition of salt the food is not only made more palatable, but the digestive juices are also increased and digestion improved. This insufficiency of salt in the food of man is seen also in that of some of the lower animals. While carnivora or flesh-eating animals find in their food all the salt they need, it is different with the herbivora or vegetable-eaters. Especially noticeable is this fact in the ruminants. Boussingault many years ago demonstrated this by a series of experiments which he conducted. He selected two sets of bullocks as nearly as possible in the same condition of health, and to both sets he gave the same food, except

that to one he gave salt, while to the other he gave none. Several months elapsed before any very marked difference could be detected, but at the end of a year, during which time the experiment continued, there were striking differences in the two sets. The bullocks that received the salt were in excellent physical condition, while those deprived of it were much inferior in every respect: their hide was rough, their hair tangled, and they were dull and apathetic. Experiments of a similar nature upon sheep have produced like results.

*Avenues of Discharge.*—Sodium chlorid is daily discharged from the body through the following excretions and in the given amounts: Urine, 13 grams; perspiration, 2 grams. There is a small amount also in mucous secretions.

**Sodium Phosphate** ( $\text{Na}_2\text{HPO}_4$ ) and **Potassium Phosphate** ( $\text{K}_2\text{HPO}_4$ ).—These salts are so intimately associated that they may be described together. They are frequently spoken of as the “alkaline phosphates,” and exist in all the solids and fluids of the body.

*Offices of Alkaline Phosphates.*—The most important office which these salts perform is to assist in giving alkalinity to the alkaline fluids—a property which, in the blood at least, is essential to life, and in some of the other fluids is necessary to the performance of their offices. The fluids of the body are, with but four exceptions, alkaline in reaction: these exceptions are gastric juice, perspiration, urine, and vaginal mucus. The following fluids are alkaline: plasma of the blood, lymph, aqueous humor, cephalorachidian fluid, pericardial fluid, synovia, mucus (except that of vagina), milk, spermatic fluid, tears, saliva, bile, pancreatic juice, and intestinal juice.

The alkalinity of the plasma of the blood is not an accidental property. The fact that the blood of all animals hitherto examined has invariably been found alkaline would seem to indicate that this condition is an important one. Bernard has shown that if an acid is injected into the blood of an animal, death will be produced even though the amount injected is not enough to make the blood itself acid. One of the properties of the blood is to carry carbonic acid gas—one of the products of the waste of the tissues—to the lungs, where it is eliminated; and experiment has shown that the alkalescence of the blood enables it to carry more of this gas than it could were it neutral in action. In discussing the alkaline carbonates it will be seen that they take part in rendering alkaline the fluids in which they occur.

*Source of Alkaline Phosphates.*—The alkaline phosphates are taken into the body in the food, of which they form a constituent part.

*Avenues of Discharge.*—After fulfilling their offices in the body these alkaline salts are discharged in the perspiration, the mucus, and the urine. In the urine a portion of the sodium phosphate



is converted into sodium biphosphate, or, as it is sometimes called, "acid sodium phosphate," which gives to the urine its acid reaction. In this fluid are discharged daily 4.5 grams of the alkaline phosphates and the sodium biphosphate.

**Sulphates.**—Sodium sulphate ( $\text{Na}_2\text{SO}_4$ ) and potassium sulphate ( $\text{K}_2\text{SO}_4$ ) are found in the blood, lymph, aqueous humor, milk, saliva, mucus, perspiration, urine, and feces. Their quantity is small, however, except in the urine, by which fluid they are discharged daily to the amount of 4 grams.

*Source of Sulphates.*—These sulphates are taken in as part of the solid food we eat and also in the water we drink. They are present in flesh, in eggs, in the cereals, and in other animal and vegetable foods. Drinking-water often contains these sulphates, and calcium sulphate as well. Sulphates are undoubtedly formed to some extent within the body. In discussing the constitution of the albuminous ingredients of the food it will be seen that one of their elements is sulphur. Some of this sulphur becomes oxidized, forming sulphuric acid, which, being a stronger acid than carbonic, displaces it from the carbonates and unites with the alkaline bases, forming sulphates.

**Carbonates.**—Sodium carbonate ( $\text{Na}_2\text{CO}_3$ ), sodium bicarbonate ( $\text{NaHCO}_3$ ), and potassium carbonate ( $\text{K}_2\text{CO}_3$ ) are salts which are known as the "alkaline carbonates," and are intimately associated with the alkaline phosphates.

*Source of Carbonates.*—These salts are, to some extent, introduced with the food, but are principally formed by the decomposition of the salts of the vegetable acids. In fruits, such as apples and cherries, and in vegetables, such as potatoes and carrots, are found malic, tartaric, and citric acids, united with sodium and potassium to form malates, tartrates, and citrates of sodium and potassium. When these fruits or vegetables are eaten, these salts are taken up by the blood, and while in the blood the organic acids are decomposed, and the bases uniting with carbonic acid, alkaline carbonates are formed, which are discharged in the urine. This accounts for the fact that after eating sufficient of such fruits or vegetables the urine becomes alkaline.

*Office of Carbonates.*—The alkalinity of the blood and of other alkaline fluids is, as has been stated, only partially due to the alkaline phosphates. In causing this reaction the alkaline carbonates have a share. In the blood of flesh-eating animals the phosphates are more abundant, this being due to the predominance of phosphates in muscular tissue, while in that of the herbivora the carbonates are in excess of the phosphates. Remembering, then, what has been said of the formation of the carbonates from the salts in fruits and vegetables, this difference in the blood is readily understood. In human blood there are both phosphates and carbonates to account for its alkalinity.



**Potassium Chlorid.**—Potassium chlorid (KCl) is found in many of the tissues, especially in the muscles, in blood-corpuscles, and in milk. This salt occurs also in gastric juice, in urine, and in perspiration. Like sodium chlorid, it is neutral in reaction and is soluble in water.

*Source of Potassium Chlorid.*—Potassium chlorid is contained in both animal and vegetable foods.

*Avenues of Discharge.*—Potassium chlorid is discharged in mucus, in urine, and in perspiration.

**Calcium Salts—Calcium Phosphate, Lime Phosphate, or Phosphate of Lime** ( $\text{Ca}_3(\text{PO}_4)_2$ ).—Next to water, calcium phosphate is the most abundant physiologic ingredient of the human body. Its total amount is 2400 grams in a man weighing 65 kilograms.

*The quantity (percentage) of calcium phosphate is as follows:*

Blood . . . . .	0.08
Urine . . . . .	0.07
Milk . . . . .	0.27
Bone . . . . .	57.6
Enamel of teeth . . . . .	88.5

The greater part of the calcium phosphate in the body is in the bones. It is estimated that 6.4 per cent. of the body is bone, and in a man weighing 65 kilograms, an average weight, there would therefore be 2400 grams of this salt. Its presence in the fluids of the body is not in noteworthy amount, except in the milk.



FIG. 80.—Partial or "green-stick" fracture (Stimson).

*Office of Calcium Phosphate.*—The principal office of calcium phosphate is to give to the bones their rigidity. During early life this salt is in small amount in the bones, and at this time the bones are soft and yielding. Later, as the phosphate and other inorganic ingredients are deposited in greater amount, these structures become more rigid and better adapted to sustain weight. In old age the inorganic constituents are in excess of the organic, and besides this difference in the proportion of organic and inorganic constituents there is the further difference that the bones of the old are lighter in weight and more porous. This is due to an increase in the size of the medullary canal and the cancellous spaces, brought about by absorption; this is especially marked at the articular head. There is also sometimes a fatty change in

the bone-tissue. These changes constitute *senile atrophy* of the bones. At an advanced period of life the bones are easily broken; while in infancy they bend but do not break, or if they do break, the fracture is not complete, but is similar to that which occurs in a green stick, and is known as the "green-stick fracture"

(Fig. 80). The flexible condition of the bones may be artificially produced by putting a long bone, like the fibula, into a jar containing dilute hydrochloric acid. The acid dissolves the inorganic salts, and, although in appearance the bone is much the same as before, it will now be found so flexible as to permit its being tied in a knot (Fig. 81). In the blood, calcium phosphate, which is insoluble in alkaline fluids, is held in solution by the albuminous constituents. Were these withdrawn the calcium phosphate would at once be rendered insoluble, and would be precipitated.

*Source of Calcium Phosphate.*—Calcium phosphate is an important ingredient of the animal and vegetable food of man. It is contained in flesh, in eggs, in milk, in wheat, in oats, in rice, in peas, in beans, in potatoes, in apples, in cherries, and in some other alimentary substances. Its presence in milk needs especial comment. As has been stated, during early life calcium phosphate is in the bones in small amount. The milk, upon which the growing child relies for its nourishment, supplies the necessary amount of this salt to give the bones their firmness and rigidity. From this statement it will be seen that the adulteration of milk with water, even though the water is pure, may be of great injury to the child. To obtain the necessary amount of calcium phosphate a certain amount of milk must be taken. If half this amount is water, the quantity of the lime-salt present will be but one-half of what it should be, and the child is consequently defrauded. Of course, if impure water is used in the adulteration, there is the additional danger of introducing the germs of disease with the milk.

*Avenues of Discharge.*—A very small amount of calcium phosphate is discharged from the body—a fact which shows its permanent character. It is discharged in the urine, in the feces, and in the perspiration.

*Calcium Carbonate* ( $\text{CaCO}_3$ ).—This salt exists in the bones to the amount of about 300 grams, in the teeth, in the blood, in lymph, in chyle, in the saliva, and sometimes in the urine. Like calcium phosphate, with which it is usually associated, it is insoluble in water; and when it exists in solution its solubility is due either to alkaline chlorids or to free carbonic acid.

FIG. 81.—Bone tied in knot.

*Calcium Fluorid* ( $\text{CaF}_2$ ) exists in the bones and in the teeth, and is of little importance.

**Magnesium Salts.**—*Magnesium phosphate* ( $\text{Mg}_3\text{PO}_4$ ) is found wherever calcium phosphate is found, and the two together are frequently spoken of as the “earthy phosphates.” It is discharged by the urine.

*Magnesium Carbonate* ( $\text{MgCO}_3$ ).—A trace of this salt is found in the blood.

**Ammonium Salts.**—Traces of ammonium chlorid ( $\text{NH}_4\text{Cl}$ ) are found in the gastric juice and in the urine.

**Iron.**—Iron is present in the hemoglobin of the blood, in the hair, the bile, and the urine. Its presence in the coloring-matter of the blood is its most striking characteristic. It exists in the blood combined with the other chemical elements, and not as an oxid. The total amount of iron in the blood of the body of a man weighing 65 kilograms is about 2.71 grams.

**Office of Iron.**—The office of iron is not understood. It is regarded as a remarkable fact that without iron chlorophyll, the green coloring-matter of plants, cannot be formed—in other words, that vegetable life is interfered with; and it is believed that its presence in the coloring-matter of the blood of an animal is equally necessary for its nutrition.

**Source of Iron.**—All animal food containing blood contains iron. In addition to this, iron is taken into the body in rye, barley, oats, wheat, peas, and strawberries.

**Avenues of Discharge.**—A small amount only of iron is discharged in the bile and the urine. After serving its purpose in the blood it is probably deposited in the hair.

**Iodin (I).**—This element occurs in the thyroid gland.

**Silicon (S).**—It is not known in exactly what form silicon exists in the body, possibly as silicic acid.

**Oxygen (O).**—This gas is absorbed from the air, and exists in the blood principally in loose combination with the hemoglobin, though some of it is doubtless free.

**Hydrogen (H).**—Hydrogen is found in the alimentary canal and in the expired air, having been absorbed by the blood from the intestine.

**Nitrogen (N).**—Nitrogen is absorbed from the air by the blood, in which it exists in a dissolved state. Some nitrogen is formed also within the body.

**Marsh-gas** ( $\text{CH}_4$ ).—This gas is found in the expired air, like hydrogen, having been absorbed from the intestines. Reiset found that thirty liters were expired in twenty-four hours.

**Ammonia** ( $\text{NH}_3$ ).—A small amount of ammonia is found in the expired air, probably derived from the blood.

**Sulphuretted Hydrogen** ( $\text{H}_2\text{S}$ ).—This gas is found in the intestines.

**Hydrochloric Acid (HCl).**—Hydrochloric acid exists in the gastric juice.

**Carbon Dioxid (CO<sub>2</sub>).**—This gas exists in many of the fluids, having been absorbed by them from the tissues. It is also present in blood and in expired air.

## CARBOHYDRATES.

This class is so called because its members contain hydrogen and oxygen in the proportion to form water, united with carbon. All substances, however, which have this composition are not carbohydrates, *e. g.*, acetic acid (C<sub>2</sub>H<sub>3</sub>OOH), nor is it to be inferred that a carbohydrate is a compound in which water is simply joined to carbon; on the contrary its constitution is quite complex.

Most of the members of this class which are of physiologic interest contain six atoms of carbon or a multiple of that number, and are, therefore, hexoses.

Carbohydrates are classified as Monosaccharids or Glucoses, Disaccharids or Saccharoses, and Polysaccharids or Amyloses.

**Monosaccharids or Glucoses.**—The members of this group have the chemical formula C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>. Those which are of special interest are Dextrose, Levulose, and Galactose.

**Dextrose** (glucose, grape-sugar, diabetic sugar) is normally found in the blood, chyle, lymph, and in very small amount in the urine. It occurs in grapes and some other fruits, and also in honey. Dextrose and levulose usually occur together. In the disease known as “diabetes mellitus” the quantity of dextrose in the blood and urine is very much increased. It is a substance of much interest, as it is in the form of dextrose that the carbohydrates of the food find their way into the blood. In its pure state dextrose is colorless and readily crystallizes; it is soluble in cold, more so in hot water. It is dextrorotatory, whence it derives its name. In alkaline solutions dextrose reduces metallic oxids, a property which is made use of in determining its presence and in measuring its quantity.

Various tests are employed for the detection of dextrose; among these are Trommer’s, the fermentation-test, and Fehling’s.

**Trommer’s Test.**—The method of applying this test is as follows:

If the presence of dextrose in an organ is to be ascertained, this should be cut into small pieces and boiled with water and sulphate of sodium, and the mixture filtered in order to have a clear solution, which is essential. Some of this should be poured into a test-tube, and a few drops of a solution of sulphate of copper added. To this a solution of caustic potash should be added, so as to make the contents of the tube distinctly alkaline. The tube should now be heated, when, if dextrose is present, just before the

boiling-point is reached, a reddish precipitate, consisting of cuprous oxide, will form. Levulose, galactose, lactose, and maltose have reducing power similar to that of dextrose, but differing in degree; thus, the power of lactose as compared with dextrose is but that of 7 to 10, while maltose has one-third less power than dextrose. Cane-, maple-, and beet-sugar have no reducing power, and must first be converted into dextrose before the reaction will take place.

*Fermentation-test.*—This test depends upon the fact that under the influence of yeast dextrose is decomposed into ethyl alcohol and carbonic anhydrid.

*Fehling's Test.*—This test is based on the same principle as that of Trommer, namely, the property possessed by dextrose to reduce metallic oxids. It is employed not only to determine the presence of dextrose, but also to measure the quantity present. The test-solution is liable to undergo changes which invalidate the result; it should, therefore, be freshly prepared, or at least be boiled before it is used. The principal change which takes place is the formation of racemic acid from the tartaric acid of the solution, and this has the same reducing action as the sugar. If after boiling the solution is clear, it may be inferred that decomposition has not taken place, and it may be used. The solution is prepared in the following manner:

34.639 grams of pure recrystallized copper sulphate are dissolved in distilled water, which is made up to 500 c.c. This solution should be kept separate from the second solution, which is made by dissolving 175 grams of crystallized Rochelle salts and 60 grams of sodium hydroxid in distilled water, and likewise made up to 500 c.c. It is found by experience that when these two solutions are mixed the resulting mixture does not keep well. When the test is to be made equal quantities of the two solutions are mixed. Prof. Bartley's method of applying this test in urine is as follows: 10 c.c. of the solution are measured into a suitable flask. To this 10 c.c. of a freshly prepared 10 per cent. solution of potassium ferrocyanid are added, and about 30 c.c. of water. The mixture is heated on a water-bath, and the urine, previously diluted with water if it contains much sugar, is run in from a faucet, drop by drop, until the blue color just disappears. The addition of the slightest excess of sugar shows itself by the solution becoming quickly brown. By careful comparative tests Prof. Bartley has found this method to be reliable and accurate provided the solution is not boiled during the reduction. The best temperature he finds to be between 80° and 90° C.

*Polariscope.*—This is also known as a *polarimeter*. It may be employed to determine the presence of dextrose. In order to understand the use of this instrument it will be necessary to consider briefly the subject of the *polarization of light*.

Common light is due to vibratory disturbances in the ether, which are propagated through it as waves, the direction of the vibrations being transverse to that of propagation. In all places where light is polarized its vibrations, still transverse to the direction of the ray, are all in one plane. Light may be polarized by transmitting it through most crystals, and if it is then transmitted through another crystal it will be observed that when this is in certain positions it will pass most easily, and that in positions at right angles to these it will be quenched entirely. It is supposed that the molecular structure of these crystals is such as to make them transparent for vibrations in one plane and opaque to those in the plane at right angles. The rotation of the plane of polarization by passing the polarized light through a crystal constitutes *rotary polarization*, and is the principle upon which the polariscope is constructed.

The crystal which polarizes the light is the *polarizer*, and that which distinguishes it is the *analyzer*.

This power to rotate the plane of polarization is possessed by other substances than crystals, such as solutions of various substances, among them being sugar; and as each of these substances rotates the plane through a different number of degrees of a circle, this fact enables the investigator to determine with what substance he is dealing. Substances having this power of rotating the plane of the polarized ray are said to be *optically active*; and those which rotate it to the right are dextrorotatory, and those that rotate it to the left, levorotatory. Inasmuch as the rotation is different for each of the component parts of white light, this kind of light cannot be used, but in its stead light of a single color, *monochromatic light*, must be used. This is usually the yellow light produced by burning a salt of sodium in the flame of a Bunsen burner.

A polariscope or polarimeter which is specially adapted to the estimation of the amount of sugar in a given solution is called a *saccharimeter*. Of these, there are various kinds, the one most commonly used being Laurent's.

*Laurent's Polarimeter*.—This and its use are described by Prof. Bartley in his *Medical Chemistry* in the following language: "Laurent's polarimeter (Fig. 82) is one of the simplest and best. In this instrument one-half of the field of vision is covered by a very thin plate of quartz, which slightly rotates the plane of the light passing through it, and causes some light to pass even when the polarizer and analyzer, both of which are Nicol prisms, are crossed. If the analyzer (*h*) is rotated so as to cause the quartz plate to become dark, the light passes through the uncovered half of the field. In an intermediate position the two halves of the field appear equally illuminated. The scale (*c*) is so graduated that this position of the analyzer is made the zero point of the instru-

ment. The slightest deviation of the analyzer from this position causes one-half of the field to appear darker and the other half lighter. There are thus presented to the eye two lights to be compared, and the instrument is thus very sensitive. Monochromatic light must be used. In some instruments the circle is divided both into degrees and sugar units, or percentages. The scale is read by means of a vernier and lens (*n*). Before using the instrument the observation tube is filled with water and placed in position between the analyzer and polarizer. If the instrument is properly adjusted, the zero mark on the vernier will correspond with the zero point of the scale when the two halves of the field are equally illuminated. The tube is then filled with the solution

FIG. 82.—The Laurent shadow polarizing saccharimeter.

to be tested and again placed between the analyzer and polarizer, when, if it is an active substance, the plane of the polarized ray coming from the analyzer will be turned to the right or to the left in passing through the solution, and one-half of the field will be lighter than the other. The amount of rotation of the plane of the polarized ray will be proportioned to the amount of the active substance in the solution. It will now be necessary to rotate the analyzer (*h*) to the right or to the left, so that the two halves of the field will again appear equally illuminated. When this has been accomplished we may read off on the vernier the degrees of the circle through which the analyzer has been rotated. In this way the amount of rotation of the polarized ray is determined.



"The *specific rotatory power* of any substance is the amount of rotation of the plane of polarized light in degrees of a circle, produced by 1 gram of the substance dissolved in 1 c.c. of the liquid, examined in a tube one decimeter in length. The specific rotatory power of a substance is obtained by dividing the angular rotation observed in the polarimeter ( $a$ ) by the length of the tube in decimeters ( $l$ ) and by the number of grams in 1 c.c. of the liquid ( $w$ ). If a sodium flame is used as a source of light, the specific rotation of the substance is that of light with wavelengths corresponding to the  $D$  line of the solar spectrum, and is usually denoted by  $(a)_d$ . Then the above statement may be expressed as follows :

$$(a)_d = \pm \frac{a}{wl}.$$

In this formula plus indicates that the substance is dextrorotatory, and minus that the substance is levorotatory. If in this formula the specific rotatory power of the substance under examination is known, and we wish to find the value of ( $w$ ), the weight of the substance, then the formula becomes,

$$(w) = \pm \frac{a}{(a)_d \times l}$$

In this formula  $a$  is the observed rotation,  $l$  the length of the tube in decimeters, which is known, and  $(a)_d$  the specific rotatory power, which has been determined for all well-known optically active substances;  $w$  can easily, therefore, be calculated. The specific rotatory powers of a few of the most important optically active substances are as follows :

Cane-sugar, $(a)_d = + 73.8^\circ$	Levulose $(a)_d = - 106^\circ$
Milk-sugar " $= + 59.8^\circ$	Egg-albumin " $= - 88.5^\circ$
Dextrin " $= + 180.8^\circ$	Serum-albumin " $= - 56^\circ$
Dextrose " $= + 56^\circ$	Gelatin " $= - 130^\circ$ .

Other tests for the presence of dextrose are Pavy's modification of Fehling's, Moore's, picric acid, and phenylhydrazin; for the methods of their use the reader is referred to special manuals on chemistry and urine-analysis.

*Fermentations of Dextrose.*—Dextrose undergoes various fermentations: (1) Alcoholic; (2) Lactic; and (3) Butyric.

1. *Alcoholic Fermentation.*—In alcoholic fermentation, under the influence of yeast, the dextrose is decomposed and ethyl alcohol and carbonic anhydrid are produced ( $C_6H_{12}O_6 = 2C_2H_5O + 2CO_2$ ). This process is at the height of its activity when the temperature is  $25^\circ C.$ ; when above  $45^\circ C.$  or below  $5^\circ C.$  it ceases. When sugar is present in the solution to the extent of more than 15 per cent. the process of fermentation will be



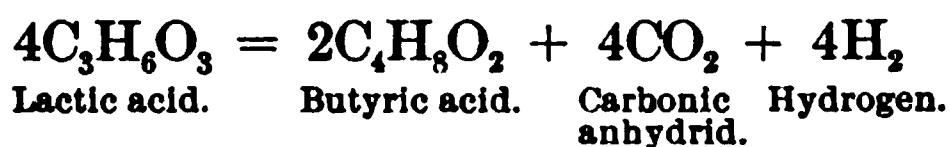
arrested by the alcohol produced, before all the sugar has been decomposed.

2. *Lactic Fermentation*.—When milk sours, the sugar which it contains is converted into lactic acid, constituting the lactic fermentation :



This fermentation is not confined to milk-sugar, but may occur also with dextrose. The change is brought about by the presence of specific micro-organisms. It is stated that there exists also in the mucous membrane of the stomach an enzyme which can change lactose, and possibly dextrose, into lactic acid.

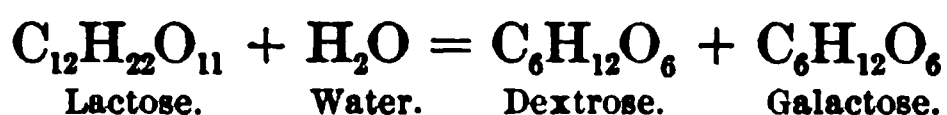
3. *Butyric Fermentation*.—When the lactic fermentation is continued for some time it is liable to pass into the butyric. This change is due to the action of a ferment (organized) upon the lactic acid. In the change, hydrogen and carbonic anhydrid are given off.



The optimum (most favorable) temperature for the lactic and butyric fermentations is from 35° C. to 40° C. When the diet consists largely of carbohydrates both these fermentations may occur in the alimentary canal.

**Levulose** (left-rotating sugar, fruit-sugar, or mucin-sugar) is found in many fruits and in honey, and occurs in small quantity in blood, urine, and muscle. It is crystallizable, but with difficulty. When cane-sugar is treated with dilute mineral acids it is decomposed into equal parts of dextrose and levulose. Cane-sugar has a dextrorotatory action on polarized light, but when changed by the acid the solution becomes levorotatory, the levorotatory power of the levulose being greater than the dextrorotatory power of the dextrose, and the cane-sugar is said to be “inverted;” hence the mixture of dextrose and levulose is sometimes spoken of as “invert-sugar.” As will be seen in the consideration of cane-sugar, “inversion” takes place in the alimentary canal. Although in many respects levulose is very similar to dextrose, still its action on polarized light serves to distinguish the two.

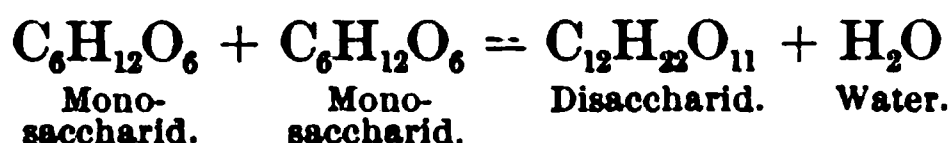
**Galactose**.—When lactose is boiled with dilute mineral acids it is changed into dextrose and galactose :



A similar change takes place under the influence of certain enzymes.

**Inosit** or muscle-sugar has been found in the muscles, lungs, liver, spleen, kidneys, and brain, and pathologically in urine. It occurs also in beans and grape-juice. Because of its sweet taste and its chemical composition it was formerly regarded as a carbohydrate, but as it has no rotatory action on polarized light, does not reduce metallic salts, and does not undergo the alcoholic fermentation, it is now regarded as belonging to the aromatic series, and not as being a carbohydrate.

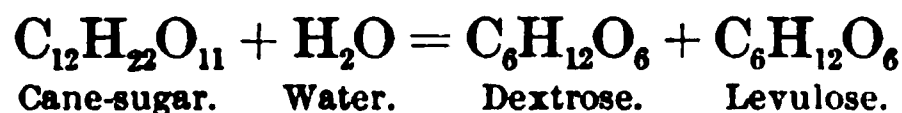
**Disaccharids or Saccharoses.**—The chemical formula representing this group is  $C_{12}H_{22}O_{11}$ . They are regarded as a condensation-product of two molecules of the monosaccharids, in which a molecule of water is lost. This may be expressed as follows :



This process is known as reversion.

The members of this group which are of physiologic importance are Cane-sugar, Lactose, Maltose, and Isomaltose.

**Cane-sugar or Saccharose.**—This sugar is not found in the human body, but it nevertheless plays an important part in the food of man. It occurs in sugar-cane, beet-root, and sugar-maple. It does not reduce metallic salts, is soluble in water, dextrorotatory, and does not undergo alcoholic, but does readily undergo lactic fermentation in presence of sour milk to which zinc oxid is added to fix the acid as formed. One of the interesting facts connected with cane-sugar is its property of “inversion,” which consists in its decomposition into equal parts of dextrose and levulose, and to this mixture the name of “invert-sugar” has been given. This change is represented chemically as follows :



and may be produced by the action of acid, as has been described under Levulose. It takes place also in the small intestine under the influence of an enzyme of the intestinal juice, namely, *invertin*. A similar inversion takes place in lactose and maltose ; thus maltose + water = dextrose + dextrose ; and lactose + water = dextrose + galactose. Invertin exists also in yeast, in which it has the same power as in the intestinal juice.

Cane-sugar cannot be taken up as such by the blood, and when injected into an animal it is eliminated unaltered in the urine. When taken in as food it is absorbed, not as cane-sugar, but as invert-sugar, into which it has been changed. This inversion is most pronounced in the small intestine ; it is claimed that it may take place also in the stomach, and that there exists in the gastric juice an enzyme which has this power.

**Lactose** (milk-sugar, sugar of milk) is found only in milk, although it may occur in the urine of lying-in women and of sucklings during the early days of lactation. It is crystallizable, less soluble in water than dextrose, and insoluble in alcohol. It is dextrorotatory, its power in this respect being the same as that of dextrose. As above noted in speaking of galactose, lactose is changed into equal parts of galactose and dextrose by boiling it with dilute mineral acids.

Lactose by itself does not undergo alcoholic fermentation with yeast, but an alcoholic fermentation does take place in milk, as when mare's milk is used for the preparation of kumyss and kephir. This fermentation is due to special ferments, the nature of which is not fully understood. In Russia kephir ferment may be purchased. Lactose readily undergoes the lactic fermentation (see Lactic Fermentation, p. 92). It is this change which takes place in the souring of milk due to the action of certain micro-organisms. The character of the change in the case of lactose is the same as in dextrose and saccharose. Lactose injected into the blood is eliminated by the urine, as are saccharose and maltose, and like them must therefore be changed in the alimentary canal during the process of absorption. This conversion, which is into dextrose and galactose, takes place under the influence of the sugar-splitting enzyme, lactase (p. 119).

**Maltose.**—When starch-paste or glycogen is treated with saliva, maltose is the principal sugar formed; prolonged treatment with pancreatic juice will produce, besides the maltose, some dextrose. Although pancreatic juice, on the one hand, acts in this manner, still the tissue of the small intestine or an extract of it has but slight action on the paste. On the other hand, the pancreatic juice rapidly changes maltose into dextrose. Maltose, like cane-sugar, injected into the blood is eliminated as maltose in the urine. From this fact it would appear that maltose is not absorbed as such in the intestine, but as dextrose. Recent researches show the presence in the succus entericus of lambs, and in the mucous membrane of the jejunum of dogs and new-born children, of an enzyme glucase which changes maltose into glucose, so that the conversion of the maltose may take place both in the cavity of the intestine and while it is passing through the intestinal walls. The action of pancreatic juice on starch in the intestine will be further discussed in the consideration of the enzymes of this fluid.

Maltose is soluble in water, but it is less soluble in alcohol than dextrose. It is crystallizable, dextrorotatory, and reduces metallic salts. Maltose is distinguished from dextrose (1) by the difference in its rotatory power on polarized light, that of maltose being greater; (2) by having a less reducing power, as when boiled with Fehling's solution only two-thirds as much cuprous oxide is separated out with maltose as with dextrose; (3) by Barfoed's reagent, which, consisting of a solution of cupric acetate in water

to which acetic acid has been added, is reduced by dextrose, but not by maltose.

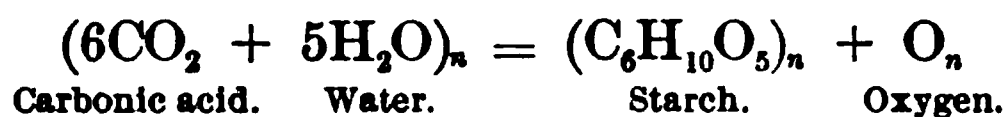
**Isomaltose.**—When starch is acted on by any of the enzymes which produce maltose isomaltose is also formed; unlike maltose, it is not directly fermentable by yeast. It is very soluble in water, and is sweet in taste. It occurs in small quantity in the urine.

**Polysaccharids or Amyloses.**—The formula of this group is  $(C_6H_{10}O_5)_n$ .

The exact formula is not determined. Chemists agree that it is not  $C_6H_{10}O_5$ , but some multiple of this, as indicated by “ $n$ ,” and that “ $n$ ” is not less than five. The members of the group are: Starch, Amylodextrin, Erythrodextrin, Achroödextrin, Maltodextrin, Glycogen, and Cellulose.

**Starch.**—Starch is not found in the human body except when it is taken in as food. It is very abundant in vegetable food. Indeed, it is said that starch exists in every chlorophyll-containing plant at some period of its existence. Starch is a substance of great interest, from the fact that it is the first organic substance produced by vegetables from inorganic matter. Animals have not the power to produce organic substances directly from members of the inorganic kingdom, but plants have this power, and they exercise it, and from the organic materials thus produced animals are nourished. Animals may change the organic matter from one form to another, as starch to sugar, but were inorganic substances alone supplied to animals they would starve.

The inorganic substances out of which the plant forms the starch are carbonic acid and water, these being taken from the atmosphere and the soil. This process is represented by the following formula:



That is, the carbonic acid and the water are decomposed, the carbon and hydrogen, with some of the oxygen, unite and form starch, while the rest of the oxygen is set free. To bring about this change there must be present solar light and the green coloring-matter, chlorophyll. If chlorophyll is absent, this change does not take place, nor does it when solar light is absent.

Starch exists in plants in the form of grains, known as “starch-grains” or “starch-granules” (Fig. 83). They present a characteristic appearance under the microscope by which they may at once be recognized. Each granule presents a number of concentric markings and varies in size and shape in different plants; by these points of difference the plant from which the granules are derived may be identified. This fact is made use of in detecting adulterations, in which cheaper kinds of starch are mixed with more expensive kinds and sold for the latter at a

higher price. The markings are caused by the arrangement of the material composing the granule in alternate layers of cellulose and granulose.

*Quantity of Starch.*—The quantity of starch (percentage) in the following food-plants is

Sweet potato . . . . .	16.05
Potato . . . . .	20.00
Beans . . . . .	33.00
Peas . . . . .	49.30
Wheat . . . . .	57.88
Oats . . . . .	60.59
Rye . . . . .	64.65
Indian corn . . . . .	67.55
Rice . . . . .	88.65

The presence of starch is determined by the addition of a little tincture of iodine, which gives a blue color. This reaction is due to the granulose, and not to the cellulose. Starch cellulose differs in some respects from ordinary cellulose, as is demonstrated by its solubility in some reagents which do not dissolve the latter.

Starch is insoluble in cold water. When boiling water is added to it in an amount twenty times its weight the granules swell and burst, and there is formed a gelatinous mass which is called "starch-paste." This paste will respond to the iodine test, showing it to be, principally at least, granulose. If the amount of water

FIG. 83.—Starch-grains.

added should be one hundred times the weight of the starch, a solution of granulose is made, the insoluble cellulose falling to the bottom of the vessel. This starch solution will likewise respond to the iodine test.

**Amylodextrin (Soluble Starch, Amidulin).**—When starch-paste, produced in the manner above described, is heated to a temperature of 40° C. on a water-bath, and saliva is then added, the paste changes from a gelatinous to a watery condition, and in this fluid soluble starch now exists. This soluble starch gives also a blue color with iodine. It filters readily, whereas starch-paste, even in dilute solution, filters with difficulty. Soluble starch is dextro-rotatory—that is, it rotates the ray of polarized light to the right. This substance is the first product of the conversion of starch into sugar by saliva; and if the action is not stopped, as it may be by boiling, the stage of soluble starch is only a temporary one, it passing quickly into that of dextrin. As will be seen hereafter, the ingredient of the saliva that changes starch into soluble starch is

an enzyme—*ptyalin*—the action being one of hydrolysis. Pancreatic juice produces the same change as does saliva; and as the action of saliva is due to the enzyme *ptyalin*, so is the action of pancreatic juice due to an enzyme, *amylopsin*.

**Erythrodextrin.**—If the action of either of these enzymes upon starch is not arrested in the soluble-starch stage, erythrodextrin is formed. The blue color caused by the action of iodine on starch gradually changes into violet, reddish violet, and then to reddish brown as the starch gradually changes to erythrodextrin. This reddish-brown color produced by iodine is the test for erythrodextrin.

**Achroödextrin.**—If the action of these enzymes is continued, a still further change in the starch takes place. It passes into the condition of achroödextrin, and iodine fails to produce any color. A further change into maltose follows the formation of achroödextrin. In the action of these enzymes upon starch outside the body the first product is a mixture of dextrin with the sugar, but within the body there is little doubt that all the starch is converted into sugar, and as such is absorbed. If starch is treated with boiling dilute acids instead of with these enzymes, the changes just described take place with far greater rapidity, and dextrose results.

**Maltodextrin.**—If diastase, the enzyme contained in malt extract, is used instead of saliva or pancreatic juice, maltodextrin is formed; and indeed it is not certain that the latter substance is not formed in addition to the erythrodextrin and achroödextrin when saliva and pancreatic juice are employed. Maltodextrin differs from the dextrans already described in being more soluble in alcohol, in being diffusible, and in responding to Fehling's test. It also passes over into maltose by the continued action of the diastase.

**Glycogen.**—The similarity between glycogen and starch has led to the term "animal starch" being applied to the former. Glycogen was first discovered in the liver, where it is normally found to the amount of between 1.5 and 4 per cent. of the weight of the organ, which may in man be increased to 10 per cent. It also exists in muscles to the amount of from 0.5 to 0.9 per cent., and it is estimated that all the muscles of the body contain as much glycogen as does the liver. It occurs also in the integument and the mucous membranes of the human embryo, in the placenta and the amnion, in white blood-corpuscles and in pus-corpuscles, in oysters and in other mollusca. For purposes of study it is usually obtained from the liver of an animal (a rabbit or a dog), in which it is stored up in amorphous granules around the nuclei of the liver-cells. Glycogen is soluble in water, and with iodine gives a port-wine color. This color does not distinguish it from erythrodextrin; but when it exists pure, as ordinarily it does not, it is



precipitated by 60 per cent. alcohol, while the dextrins are not precipitated. Watery solutions are dextrorotatory.

In general it may be said that the action of the enzymes and of boiling acids upon glycogen is the same as upon starch. The glycogen of the liver becomes converted, by physiologic processes, into liver-sugar, which is regarded as identical with dextrose. In this process probably no maltose is formed, such as occurs in the artificial hydrolysis already described. This difference would seem to indicate that in the liver-cells there is no enzyme to which this action can be attributed; for, so far as can be judged, most enzymes produce maltose, and not dextrose, and up to the present time no dextrose-producing enzyme has been obtained from the liver.

**Cellulose.**—Nowhere in the animal body is cellulose found, but it exists in many of the vegetable alimentary principles upon which man relies for his nutrition. As has already been stated, it is a constituent of the starch-granule, and so covers the granulose that the digestive fluids cannot reach it. When starch is boiled the granules burst, and thus access to the granulose is given. It has recently been suggested that there is in the intestinal canal, formed by the epithelial cells, an enzyme which has the power of causing a digestion of the cellulose. But the evidence of the existence of such an enzyme is very meagre. The disappearance of the cellulose is probably due to the action of bacteria, all the products being unknown, though marsh-gas, acetic and butyric acids are among them. This change takes place especially when vegetables, such as celery and lettuce, and fruits are eaten whose cell-walls are tender and have not yet become lignified or woody in character. Lignin is the name applied to cellulose in this advanced stage. In the human intestine from 4 to 60 per cent. of the cellulose taken in is dissolved. It doubtless has very little nutritive value, but is regarded as increasing by its local action intestinal peristalsis and keeping the bowels free. In the rabbit its absence from the food results in death, inflammation of the intestine being caused thereby; but if horn-shavings, which are excreted unchanged, are substituted for cellulose, the animal maintains its health. The cellulose of some plants, such as the date, is regarded as a reserve material to be made use of in germination.

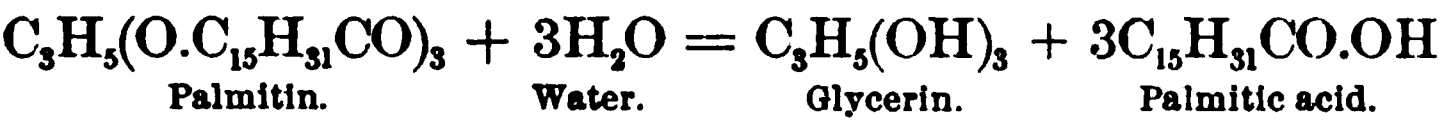
The presence of cellulose is recognized by the fact that when treated with strong sulphuric acid it becomes converted into a substance that is colored blue by iodine. Schulze's reagent is another test for its presence. This test consists in the production of a blue color when the substance is treated with iodine dissolved to saturation in a solution of chlorid of zinc to which potassium iodid has been added.

THE FATS.

The chemical elements entering into the composition of the fats are carbon, hydrogen, and oxygen. The fats are widely distributed throughout the human body. The percentage in the solids and fluids is as follows :

Sweat . . . . .	0.001	Cartilage . . . . .	1.8
Vitreous humor . . . . .	0.002	Bone . . . . .	1.4
Saliva . . . . .	0.02	Crystalline lens . . . . .	2.0
Lymph . . . . .	0.05	Liver . . . . .	2.4
Synovia . . . . .	0.06	Muscles . . . . .	3.3
Liquor amnii . . . . .	0.06	Hair . . . . .	4.2
Chyle . . . . .	0.2	Brain . . . . .	8.0
Mucus . . . . .	0.3	Nerves . . . . .	22.1
Blood . . . . .	0.4	Adipose tissue . . . . .	82.7
Bile . . . . .	1.4	Marrow . . . . .	96.0
Milk . . . . .	4.3		

Fats are regarded by chemists as composed of fatty acids and glycerin, and are called *glycerids* or *glyceric ethers*. When treated with superheated steam and mineral acids, and in the human body under the influence of steapsin, the lipolytic enzyme of the pancreatic juice, the fats are decomposed into glycerin and the respective fatty acid. This change is expressed by the following formula, palmitin being taken as an example :



There are three varieties of fats: Olein,  $\text{C}_3\text{H}_5(\text{OC}_{17}\text{H}_{33}\text{CO})_3$ ; palmitin,  $\text{C}_3\text{H}_5(\text{OC}_{15}\text{H}_{31}\text{CO})_3$ ; and stearin,  $\text{C}_3\text{H}_5(\text{OC}_{17}\text{H}_{35}\text{CO})_3$ . These differ in several particulars, one of the most important being their melting-points: Olein melts at 5° C.; palmitin, at 45° C.; and stearin, at from 53° to 66° C. Their respective acids are *oleic*, *palmitic*, and *stearic*.

Fats are characterized by being insoluble in water, slightly soluble in alcohol, and very soluble in ether and chloroform. All fats are mixtures of the three varieties, the difference in the consistency of any given fat depending upon the proportion in which the neutral fats are present. Thus in the more solid fats, such as suet, stearin predominates, while in the fluid fats it is olein which is in excess. The latter exists in human fat to the amount of from 67 to 80 per cent. When fats decompose or become "rancid," propionic, acetic, and formic acids are produced.

**Adipocere.**—It sometimes happens that when bodies are disinterred, instead of being found in a condition of putrefaction, they are discovered to have been changed into *adipocere* or *grave-wax*. This is a peculiar substance of a waxy nature, and consists of calcium soaps, of which the fatty acids are palmitic and stearic. Acid ammonium soap has been found in some cases. This change



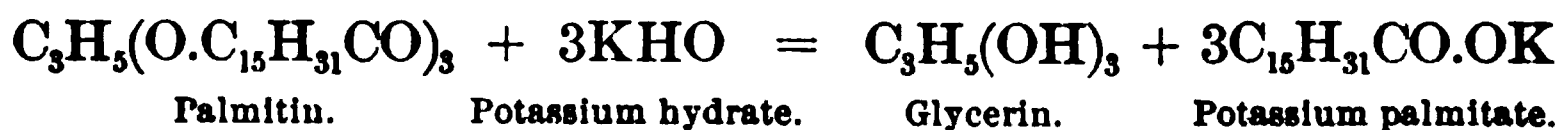
occurs in bodies which have been interred in moist soils, or have been in water for a considerable time after death.

**Source of Fat in the Human Body.**—Human fat is derived from the fats, the carbohydrates, and the proteids of the food. In fatty meats, nuts, eggs, milk, and other foods more or less fat exists as a constituent, and undoubtedly contributes to the formation of the fat of the body. That the fat of the food can be deposited as such in the tissues was for a time denied, but it has been shown by feeding starved dogs upon such fatty foods as rapeseed oil, linseed oil, or mutton tallow, that they will not only take on fat, but that some of the kind of fat which enters into their food is deposited as such in their tissues. Food containing starch and sugar is also fattening in its nature, and persons who have an excess of fat are placed upon a diet containing a minimum of these ingredients. Herbivorous animals—the cow, for instance—rely entirely upon vegetable food for their support, and it is the carbohydrates which this contains that are converted into the fat of their milk and that which covers their muscles. It is doubtless from the carbohydrates that most of the fat is produced. That proteid food will also produce fat is shown by the amount of the latter which carnivorous animals put on.

**Offices of Fat.**—The offices which fat subserves in the human body are manifold: (1) It protects the underlying parts from injury, as in the palm of the hand and the sole of the foot; (2) it serves as a lubricator, as in the sebaceous matter poured out upon the skin, which it keeps soft and pliable; (3) it acts as a non-conductor of heat, aiding in the retention within the body of the vital heat which would otherwise be lost so rapidly as to produce injurious results; (4) it serves as a reservoir when the supply of food is cut off or diminished; thus in wasting diseases the fat deposited in various parts of the body is absorbed and contributes to its nutrition; (5) it is a source of energy and of heat through its oxidation, the final products of which are  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .

**Important properties of fats**, besides those already mentioned, which deserve special consideration, are two—that of forming a soap and that of forming an emulsion.

**Saponification.**—Fats are saponifiable—*i. e.*, capable of being converted into a soap. Thus when heated with a caustic alkali the fat is split up as already described, into glycerin and a fatty acid, and the latter unites with the base, the compound resulting being a soap. Thus if palmitin and potassium hydrate are the fat and alkali used, the product is a soap whose chemical composition is potassium palmitate. This is expressed in the following formula:



In like manner stearin would form a stearate, and olein an oleate. The sodium soaps are "hard," and those of potassium are "soft." In the discussion of intestinal digestion it will be seen that the process of saponification takes place in the small intestine, and that the soap there formed aids in the important functions of that portion of the alimentary canal (p. 236).

**Emulsification.**—Besides being saponifiable, fats are also emulsifiable—capable of forming an emulsion. If oil and water are poured into a test-tube, they will at once separate, the oil floating on the water. If the mouth of the tube is closed by the thumb and the tube firmly shaken, the oil and water will form a milky mixture, but will separate again when the agitation ceases; if a small amount of an alkali is added and the tube is again shaken, separation will not take place as before, but the milky appearance will continue for some considerable time. If a drop of the mixture is placed under the microscope, it will be found that the oil-globules have been broken up into an exceedingly fine state of subdivision, some of the particles being too small to measure even with a very high magnifying power. This more or less permanent subdivision and suspension of the oil-globules constitutes an emulsion. The change is not a chemical one, but purely physical. A similar process takes place in the small intestine during intestinal digestion (p. 237) and is regarded by some as a necessary preliminary to the absorption of fat (p. 261).

The fat in milk is in an emulsified condition; consequently milk may be regarded as a natural emulsion.

**Lecithin.**—This substance may be regarded as a fat, and from the fact that it contains phosphorus it has been spoken of as "phosphorized fat." Its formula is  $C_{42}H_{84}NPO_9$ . It is decomposable into glycerin, stearic acid, phosphoric acid, and an alkaloid, cholin.

Lecithin occurs in the brain and other nervous tissues, considered by some authorities as here produced by decomposition of protagon, in yolk of eggs, blood-corpuscles, semen, bile, and milk. It is also one of the constituents of protoplasm.

**Cholesterin.**—This substance bears some resemblance to the fats in that it is insoluble in water, but soluble in ether, hot alcohol, and chloroform. It is a constituent of protoplasm, and is also found in blood-corpuscles, bile, serum, and white substance of Schwann. In the blood it is in combination with oleic and palmitic acids. It forms *esters* with fatty acids, and as such exists in the fatty secretions of the skin. Lanolin, the fat obtained from sheeps' wool, is said to be rich in esters, and these are very resistant to the action of bacteria.

PROTEIDS.

These ingredients are the most important constituents of muscles, glands, nervous tissue, and blood ; indeed, it has been said of them that none of the phenomena of life occurs without their presence. Of them Gamgee says: "They are highly complex, and, for the most part, uncrystallizable compounds of carbon, hydrogen, oxygen, nitrogen, and sulphur (phosphorus is also sometimes present), occurring in a solid, viscous condition, or in solution in nearly all the solids and liquids of the organism. The different members of the group present differences in physical, and to a certain extent even in chemical properties. They all possess, however, certain common chemical reactions, and are united by a close genetic relationship."

Their percentage-composition is as follows :

Carbon . . . . .	50	to	55
Nitrogen . . . . .	15	"	18
Hydrogen . . . . .	6.9	"	7.8
Oxygen . . . . .	20	"	28.5
Sulphur . . . . .	0.8	"	2

When proteids are burned there is found in the ash a certain quantity of salts ; from the ignition of egg-albumin, for instance, chlorids of sodium and potassium result, and salts of calcium, magnesium, and iron. It is still undecided whether these salts are integral parts of proteids or impurities, probably the latter.

The percentage of proteids in some of the solids and liquids of the body, and their wide distribution, are shown by the following table :

Cerebrospinal fluid . . . . .	0.09	Chyle . . . . .	4.09
Aqueous humor . . . . .	0.14	Blood . . . . .	8.56
Liquor amnii . . . . .	0.70	Spinal cord . . . . .	7.49
Intestinal juice . . . . .	0.95	Brain . . . . .	8.63
Pericardial fluid . . . . .	2.36	Liver . . . . .	11.64
Lymph . . . . .	2.46	Thymus . . . . .	12.29
Pancreatic juice . . . . .	3.33	Muscle . . . . .	16.18
Synovia . . . . .	3.91	Tunica media of arteries . . . .	27.38
Milk . . . . .	3.94	Crystalline lens . . . . .	38.80

Various attempts have been made to ascertain the constitution of the proteids and give a formula for them, but the differences in the results obtained by equally competent chemists have been so great that practically nothing worthy of quoting is on record. There is no doubt, however, that the molecules are very large.

**General Properties of Proteids.**—All are insoluble in alcohol and ether. They are also said to be soluble with the aid of heat in concentrated mineral acids and caustic alkalies ; but inasmuch as this is accompanied with decomposition of the pro-

teids it is a question whether it can be regarded as a true solution.

**Action on Polarized Light.**—All proteids are levorotatory (see p. 89), but the degree of rotation varies considerably. The following table gives the specific rotatory power of several of the proteids :

Proteid.	Value of $(\alpha)_d$ .
Serum-albumin . . . . .	— 56° to — 68°
Egg-albumin . . . . .	— 35.5° “ — 38.08°
Lactalbumin . . . . .	— 36° “ — 37°
Serum-globulin . . . . .	— 59.75°
Fibrinogen . . . . .	— 43°
Alkali-albumin . . . . .	— 62.2°
Syntonin (from myosin) . . . . .	— 72°
Casein (dissolved in $\text{MgSO}_4$ solution) . . . . .	— 80°
Various proteoses . . . . .	— 70° to — 80°

**Color-reactions.**—Certain color-changes which take place when proteids are treated with various reagents have been made use of to detect their presence or absence. Although chemists have determined the elements which go to make up proteids, they have not as yet determined their constitution. They have ascertained that proteids undergo changes or decomposition in the body, as a result of which carbonic acid, water, and urea are finally formed, and that there are various intermediate products, such as leucin, creatin, uric acid, and ammonia. It has also been determined that by chemical means proteids can be decomposed into a great variety of substances: some of these are ammonia, carbonic acid, amins, leucin, and aromatic compounds. Of this last class, the aromatic compounds, there are three groups: 1. The *phenol* group, including tyrosin, phenol, and cresol; 2. The *phenyl* group, including phenylacetic and phenylpropionic acids; and 3. The *indol* group, in which are indol and skatol. It is upon this class of substances, the aromatic compounds or radicles, that the color-reactions of proteids depend.

**Xanthoproteic Reaction.**—When a solution of proteid, to which a few drops of nitric acid have been added, is boiled, it becomes yellow, and if ammonia is added the yellow color changes to orange.

**Millon's Reaction.**—Proteids when heated with Millon's reagent give a white precipitate which becomes brick red on cooling. This reagent is prepared by dissolving mercury in nitric acid and adding water. The precipitate which forms is allowed to settle, and the fluid is the reagent. Very small amounts of proteids give the red color without the precipitate.

**Plotrowski's or Biuret Reaction.**—When many proteids are mixed with an excess of concentrated solution of sodium hydrate and one or two drops of a dilute solution of cupric sulphate, a violet color is produced which becomes deeper on boiling; with peptones and proteoses the color produced is rose red. Biuret is the substance

formed when urea is heated, ammonia being given off in the process. The following formula expresses the change which takes place :



Since the rose-red color is produced by biuret, the reaction is also called by this name.

**Crystallization.**—While it is true that proteids as a class are not crystallizable, or perhaps it would be more correct to say have never been crystallized, still there are exceptions to this rule, inasmuch as crystals of globulin or vitellin have been seen in the aleurone grains of seeds and in the yolk of the egg of fishes and amphibians. Egg-albumin, serum-albumin, and caseinogen have also been made to crystallize. This may be demonstrated in the following way: To a solution of egg-albumin, white of egg, add half its volume of a saturated solution of sodium sulphate, precipitating the globulin, which is removed by filtration. In the filtrate, exposed to the air for some days, during which evaporation takes place, minute spheroidal globules and needles will form, which are the crystals of the proteid. Acetic acid hastens the crystallization and produces better crystals.

**Non-diffusibility.**—As a class, proteids are not diffusible; to this rule peptones are the exception. In order that this property of proteids may be understood, it will be advantageous to the student to describe the processes of *diffusion* and *osmosis*. If a solution of common salt is placed in a vessel and water is carefully poured on the surface of the salt solution, the salt will pass into the water, and in a short time the contents of the vessel will be of the same composition throughout. This passage of the salt into the water is *diffusion*, and in this instance the process takes place very quickly. Not so, however, would be the case if a solution of albumin was substituted for the solution of salt; the same phenomenon would occur, but would require a much longer time. When liquids are separated by a membrane the diffusion which takes place through it is *osmosis*.

It is important to understand osmosis and the conditions under which it takes place, as without this knowledge many of the processes which occur in the human body would be unintelligible; at the same time it must be said that osmosis does not occupy the prominent place it once did in explaining phenomena connected with absorption; investigations have shown that the passage of the products of digestion from the alimentary canal into the blood is not a simple diffusion through a passive membrane, but that cell-activity must be largely taken into account.

Fig. 84 represents a jar, A, which contains distilled water. Within this, resting on a tripod, is an *osmometer*, an expanded glass vessel, B, closed by a piece of parchment, C, from the top

of which rises a graduated tube. The osmometer is supposed to contain a solution of some salt; sulphate of copper, for instance. In a short time after the apparatus has been put in the condition described, the water in the jar will become bluish from the passage into it of some of the sulphate of copper from the osmometer. This outward passage of the salt is *exosmosis*. In the graduated tube the fluid in the osmometer will be seen to rise higher and higher, due to the passage of the distilled water from the jar through the parchment into the osmometer, lowering the level of the water in the jar. This inward passage constitutes *endosmosis*. This continues until the proportion of sulphate of copper is the same in both jar and osmometer; in the meantime, however, the amount of water in the osmometer is greater than at the beginning of the experiment. If different solutions are used than those mentioned, the results as to time, amount of endosmosis, etc., will vary materially from those described.

This subject was exhaustively studied by Graham, who objected to the use of the terms "*endosmosis*" and "*exosmosis*," believing that there was in reality but one current, the inward one; and he therefore used only the terms *osmosis* and *osmotic*. In the outward passage of the salt he held that it was the particles of salt which passed, but not the water holding them in solution.

A second experiment may be performed which illustrates another phase of osmosis. From one end of a hen's egg the shell is to be carefully removed so as to leave the membrane uninjured. Through the other end, into the interior of the egg, a glass tube is to be passed, and the place at which it enters the egg closed with sealing-wax. The egg is then to be placed in a wine-glass containing distilled water. The water in the wine-glass passes through the membrane into the egg, and the yolk will be seen to rise in the glass tube; at the same time it will be noted that the water in the wine-glass is diminished. After a time a solution of nitrate of silver may be dropped into the wine-glass, and immediately a whitish precipitate forms, consisting of silver chlorid. This is a proof that the chlorid of sodium, or common salt, which was a constituent of the egg, has passed through the membrane into the water. Other tests will show that the other salts have also passed out, but that little of the albumin has come through. From this experiment it will be seen that substances act

FIG. 84.—Graham's osmometer.



differently with reference to passing through membranes; those which pass through readily Graham denominated *crystalloids*; while those that pass not at all or with difficulty, he called *colloids*, a term which does not necessarily imply that the substances which are called by that name do not crystallize, for, as we have seen, egg-albumin does crystallize, though salts are crystalloids and egg-albumin a colloid. This principle is the same as *dialysis*, or the separation of crystalloids from colloids in a *dialyzer*, an apparatus constructed like the osmometer, already described.

As already stated, proteids, except proteoses and peptones, are not diffusible, or, to put the statement affirmatively, are colloids—*i. e.*, they do not readily pass through animal membranes; and this principle of dialysis is employed to separate them from crystalloids, such as sugar and salts. This may be demonstrated by putting a saline solution of albumin and globulin, as, for instance, blood-serum, in a dialyzer, the vessel outside containing distilled water; the salts diffuse, leaving the albumin and globulin behind. The albumin, being soluble in water, remains in solution, and, being colloid, does not diffuse; the globulin, requiring the salts to hold it in solution, is precipitated because the salts have diffused.

Proteoses are diffusible, but less so than peptones; protoproteose more than deuteroproteose, and this more than heteroproteose, so that the order of diffusibility would be peptones, protoproteose, deuteroproteose, and heteroproteose. It is to be borne in mind that diffusibility is a relative term, and that when peptones are said to be readily diffusible the idea intended to be conveyed is, that when compared with other proteids they exhibit this property. If, however, they are compared with salts, their diffusibility is low.

The explanation formerly given to account for the non-diffusibility of proteids was that they were not crystallizable; but since the discovery of the fact that some of them do crystallize, this explanation is abandoned, and for it is substituted that of the great size of their molecule. The molecular weight of some of these proteids has been determined, and this confirms the theory just enunciated: thus peptone, very diffusible, has a molecular weight of 400 or less; protoproteose, less diffusible, of 2467 to 2600; and deuteroproteose, still less diffusible, of 3200.

**Precipitation.**—As a class, proteids in solution are precipitable by certain reagents, of which the number is considerable. Some of the principal precipitants are: Nitric acid, picric acid, acetic acid with potassium ferrocyanid, acetic acid with excess of sodium or magnesium sulphate or sodium chlorid, when boiled with the solution of the proteid, mercuric chlorid, silver nitrate, lead acetate, tannin, and alcohol. Tannin and alcohol will precipitate peptone, but most of the others will not.

**Classification of Proteids.**—The proteids are classified as follows:

Albumins . . . . .	{ Serum-albumin. Egg-albumin. Lactalbumin. Myo-albumin.
Albuminates . . . . .	{ Acid-albumin. Alkali-albumin.
Globulins . . . . .	{ Serum-globulin (paraglobulin). Fibrinogen. Paramyosinogen. Myosinogen. Lactoglobulin. Crystallin.
Nucleoproteids . . . . .	{ Caseinogen. Vitellin.
Proteoses . . . . .	{ Albumoses. Globuloses. Vitelloses. Caseboses. Myosinoses, etc.
Peptones . . . . .	{ Parapeptone. Propetone. Hemipeptone. Antipeptone, etc.
Coagulated Proteids . . .	{ Fibrin. Myosin. Casein.
Poisonous Proteids.	

### ALBUMINS.

These are sometimes described under the name of *native albumins*. They are soluble in water, dilute saline solutions, and saturated solutions of sodium chlorid and magnesium sulphate. When their solutions are saturated with ammonium sulphate the albumins are precipitated, and when heated to a temperature of about 70° C. they are coagulated. It is important to distinguish between *precipitation* and *coagulation*. As just stated, the albumins are precipitated by ammonium sulphate; but they still retain their identity and solubility. When, however, they are coagulated they become insoluble and are changed into a form known as



*coagulated proteid.* Some proteids are precipitated by certain reagents, and not by others, and this fact is made use of to distinguish the proteids from one another.

The following table gives the temperature at which the different albumins coagulate :

Albumins.		Temperature.
Serum-albumin	( $\alpha$ ) . . . . .	73° C.
"	( $\beta$ ) . . . . .	77°
"	( $\gamma$ ) . . . . .	84°
Egg-albumin . . . . .		73°
Lactalbumin . . . . .		77°
Myo-albumin . . . . .		73°

**Serum-albumin.**—The fluid of blood in its normal condition is *plasma* ; after coagulation, *serum*. The albumin of blood remains in the serum after blood has coagulated, and hence is known as serum-albumin. When to plasma or serum is added an equal amount of a saturated solution of ammonium sulphate, the fluid is said to be half saturated with ammonium sulphate. In this condition the globulins and nucleoproteids are precipitated, but not the albumin. The same result is obtained by completely saturating it with magnesium sulphate. If now the fluid is filtered, the globulins and nucleoproteids will be filtered out, and the filtrate (the liquid which has passed through the filter) may be put into a dialyzer, and the salts will thus be removed, leaving only the serum-albumin. The fact that exposure of serum-albumin to different temperatures (about 73° C., 77° C., and 84° C.) results in three separate coagulations indicates that what is called serum-albumin is in reality three different substances or forms, which are called respectively  $\alpha$ -albumin, which coagulates at 72° to 75° C. ;  $\beta$ -albumin, coagulating at 77° to 78° C. ; and  $\gamma$ -albumin, coagulating at 83 to 86° C. Halliburton, to whom we owe this information, has ascertained that in the plasma of the horse, ox, and sheep  $\alpha$ -albumin is absent, while  $\beta$ -albumin and  $\gamma$ -albumin are present ; in the reptiles, amphibians, and fishes, the blood of which he examined, only  $\alpha$ -albumin was normally found, while in that of man and of all other mammals and birds all three were present.

Magnesium sulphate does not precipitate serum-albumin, while it does serum-globulin, so that by this reagent the two may be separated, the salt being added in crystals until the solution is completely saturated ; or, as stated, half-saturation with ammonium sulphate will bring about the same result.

The specific rotatory power of solutions of serum-albumin is — 56°.

**Egg-albumin.**—As its name implies, egg-albumin is obtained from the white of egg. If much of it is taken in the food, or if it is injected into the blood, part of it appears in the urine. When shaken with ether it is precipitated. Nitric acid, heat, and

the prolonged action of alcohol coagulate egg-albumin ; and mercuric chlorid, nitrate of silver, and lead acetate precipitate it, forming insoluble compounds.

**Lactalbumin.**—This physiologic ingredient occurs in the milk together with two other proteids, caseinogen and lactoglobulin. Half-saturation with ammonium sulphate precipitates the caseinogen and lactoglobulin, and the lactalbumin which remains in solution may be precipitated by saturation with sodium sulphate. A temperature between 70° and 80° C. (about 77° C.) will coagulate it. Unlike serum-albumin, it consists of but a single proteid. Its percentage composition is: C, 52.19 ; H, 7.18 ; N, 15.77 ; S, 1.73 ; O, 23.13.

**Myo-albumin.**—This is the albumin of muscle, and resembles serum-albumin.

### ALBUMINATES.

The members of this group are sometimes described under the name *derived albumins*, because they are derived from albumin by the action of acids or alkalies. Globulins, when treated in the same manner, also produce albuminates. When a mineral substance is added to a solution of albumin, a new compound is formed, which is denominated an albuminate of the mineral, but as such products are not physiologic ingredients we shall not consider them. Albuminates are insoluble in water and neutral solutions containing no salt ; soluble in acids, alkalies, and dilute saline solutions ; precipitated when saturated with sodium chlorid or magnesium sulphate ; and are not coagulated by heat.

**Acid-albumin.**—This is the product of the action of a dilute acid—hydrochloric, for instance—upon an albumin. In this conversion the proteid undergoes important changes. Its solution is not coagulated by heat, and when it is neutralized the proteid is precipitated. The conversion from the native to the acid-albumin is gradual, and is hastened by heat, care being taken that the temperature is not sufficiently high to coagulate it. Globulins are likewise converted into acid-albumins by the same means, but more readily, while coagulated proteids or fibrin require the acid to be concentrated.

By some writers the term syntonin is applied to the particular acid-albumin resulting from the globulin myosinogen ; while others use it as a synonym for acid-albumin in general.

The point of special physiologic interest in connection with acid-albumin is that in the process of stomach-digestion it is one of the products.

**Alkali-albumin.**—As acids acting upon albumins and globulins produce acid-albumin, in a similar manner alkalies produce alkali-albumin. There is an interesting historic point in connection with this proteid. Mulder found that by heating albumin

with caustic potash a product was obtained which he regarded as the basis of all albuminous substances, and to which he gave the name of "protein." Under this theory proteids are supposed to be modifications of protein, but the theory is an obsolete one, and Mulder's protein is nothing more than alkali-albumin. Alkali-albumin is produced in the small intestine when the albumins and globulins of the food are acted upon by the alkali of the pancreatic juice.

### GLOBULINS.

The members of this group are soluble in dilute saline solutions, as, for instance, 1 per cent. sodium chlorid, insoluble in water, concentrated solutions of sodium chlorid, magnesium sulphate, and ammonium sulphate, and are coagulated by heat.

The following table gives the temperatures at which the important globulins coagulate :

Globulins.	Temperature.
Serum-globulin . . . . .	75° C.
Fibrinogen . . . . .	56°
Myosinogen . . . . .	56°
Crystallin . . . . .	78°

**Serum-globulin (Paraglobulin).**—*Fibrinoplastin* is another name for this proteid, given to it at a time when it was believed that it was connected with the process by which fibrin was formed, as in the coagulation of blood. It exists in human plasma to the extent of about 3 per cent. It exists also in lymph and chyle.

**Fibrinogen.**—This globulin is associated with serum-globulin in plasma, lymph, and chyle. It is a substance of great interest, inasmuch as upon its presence the coagulability of blood depends, a process in which the soluble fibrinogen becomes insoluble fibrin. It is precipitated by half-saturating with sodium chlorid, and by this means may be separated from serum-globulin.

**Fibrin.**—Fibrin is obtained by whipping blood with twigs or wires. The material that clings to these is fibrin together with some of the blood-corpuscles, which become entangled in its meshes. These may be washed out in running water. When examined with the microscope fibrin is seen to be made up of threads which intertwine with one another, forming a network. Dry fibrin is obtainable from blood to the amount of from 0.2 to 0.4 per cent. of its weight. Its percentage-composition is C, 52.68; H, 6.83; N, 16.91; S, 1.10; O, 22.48. It is soluble in 5 to 10 per cent. solutions of sodium chlorid, sodium sulphate, magnesium sulphate, and some other salts. It swells in hydrochloric acid of 0.2 per cent. strength and becomes acid-albumin and proteoses. If pepsin is also present, this change takes place more quickly, the fibrin becoming converted into two globulins, one coagulating at 56° C. and the other at 75° C., and then becoming acid-albu-

min, proteoses, and finally peptones. Trypsin acts as does pepsin, except that the reaction must be alkaline, not acid, the products being alkali-albumin, proteoses, and peptones.

In speaking of the ash produced when fibrin is burnt, Schäfer says that it invariably contains lime, but not more than other proteids, nor more than the fibrinogen from which it is formed. This fact completely disposes of the theories of coagulation which assume that fibrin is merely a combination of fibrinogen with lime, such as those of Freund, Arthus, Pekelharing, and Lilienfeld.

**Myosinogen.**—This globulin occurs in muscular tissue, and in the condition called *rigor mortis* coagulates, and in this condition is *myosin* or muscle-clot. A similar change, *heat-rigor*, occurs when muscle is heated, coagulation taking place when the temperature reaches  $47^{\circ}$  to  $50^{\circ}$  C.; and a second coagulation at  $56^{\circ}$  C. This is due to the fact that there are two globulins: paramyosinogen which coagulates at the lower, and myosinogen at the higher temperature.

**Lactoglobulin.**—This proteid is found in cows' milk in such minute quantity that it has escaped the analyses of excellent chemists.

**Crystallin.**—The proteid matter of the crystalline lens is crystallin, and exists in that structure to the amount of 34.93 per cent. Two varieties of crystallin are described:  $\alpha$ -crystallin and  $\beta$ -crystallin, differing in composition, specific rotatory power, and coagulation-point. The former is more abundant in the outer portion of the lens; the latter, in the inner.

### NUCLEOPROTEIDS.

These substances are composed of nucleins and proteids, and occur in the nuclei and protoplasm of cells. Nucleins have been obtained from the nuclei of pus-corpuses, spermatozoa, yolk of egg, yeast, liver, brain, and cows' milk. The term nucleins is used rather than nuclein because there are several of these substances, differing in solubility and chemical composition. They are divided by Hoppe-Seyler into three groups:

1. **Nucleins** which consist only of *nucleic acid*, whose formula is not definitely known, but is approximately  $C_{40}H_{54}N_4O_{17}(P_2O_5)_2$ . Indeed, nucleic acid is itself probably not a single substance, no less than four having been found by investigators. This acid does not give the reactions of proteid, but is characterized by its great affinity for basic dyes, such as methyl-green (see Karyokinesis, p. 28). Nucleins of this group occur in spermatozoa.

2. **True Nucleins.**—These occur in the nuclei of cells, and on decomposition yield proteid, xanthin bases (hypoxanthin, xanthin, guanin, adenin), and phosphoric acid. The true nucleins, which contain the most nucleic acid, are obtainable from the

chromatin fibers of the nucleus ; those which occur in the nucleoli contain less nucleic acid.

**3. Pseudonucleins.**—These are sometimes called *paranucleins*, and are obtainable from the nucleoproteids, such as caseinogen and vitellin. They yield none of the bases as do the true nucleins, but only proteid and phosphoric acid.

The nucleoproteids are divided into two groups: 1. Those which yield true nucleins on gastric digestion, and to which Hammarsten restricts the name “nucleoproteids;” and 2. Those which yield pseudonucleins on gastric digestion, called by Hammarsten “nucleo-albumins.” In this latter group are caseinogen and vitellin. To make this *résumé* complete, mention should be made of the phospho-glucoproteids. A glucoproteid is a compound of proteid with a carbohydrate, and includes mucins among other substances. From mucins a carbohydrate may be obtained called *animal gum*, which when acted upon by a dilute mineral acid is converted into a reducible but non-fermentable sugar having the formula  $C_6H_{12}O_6$ . Most of the glucoproteids contain no phosphorus, but some do, and these constitute the phospho-glucoproteids. There is some evidence to show that from many of the proteids (acid- and alkali-albumin, serum-albumin, serum-globulin) a reducing substance may be obtained, which may be a carbohydrate.

**Caseinogen.**—This was formerly regarded as an alkali-albumin, but is now placed among the nucleoproteids ; and if we accept the classification of Hammarsten, it would be placed among the nucleo-albumins, for the reason that on gastric digestion it yields pseudonuclein.

Caseinogen is the most abundant proteid of milk, the two other proteids being lactoglobulin and lactalbumin, and may be obtained from it by saturation with sodium chlorid or magnesium sulphate, or by half-saturation with ammonium sulphate. It is not coagulated by heat. Human caseinogen has the following percentage-composition: C, 52.24; H, 7.31; N, 14.9; P, 0.68; S, 1.17; O, 23.66; and yields no pseudonuclein on gastric digestion. When acted upon by rennet caseinogen coagulates, becoming *casein*, which is soluble in dilute alkalies, such as lime-water. Rennet is obtained from the stomach of the calf, and owes its property of coagulating caseinogen to the enzyme *rennin*, also called *chymosin*. Upon the addition of rennet to cows' milk a *curd* or clot is formed, which consists of casein and the fat of the milk ; the liquid portion of the milk, after the curd is formed, is *whey*, consisting of water holding in solution the proteids, lactoglobulin and lactalbumin, lactose, and the salts. Another proteid, *whey-proteid*, is produced from the decomposition of that portion of the caseinogen which is not changed into casein. The curd of human milk is of a softer and more flocculent character than that of cows' milk, and to render the curd of the latter more like that

of the former, and thus aid digestion in the infant, lime-water or barley-water is sometimes added, simple dilution with water or boiling the milk producing the same effect.

One essential condition for coagulation of caseinogen is the presence of calcium salts; and if these salts are precipitated, as they may be by the addition of potassium oxalate, coagulation does not take place. The details of the coagulating process are as follows: The enzyme, rennin, converts the caseinogen into soluble casein, which is then precipitated by the calcium salts; the curd being probably caseate of lime.

**Vitellin.**—This is the principal constituent of the yolk of egg. It is described by some writers as containing phosphorus; others regard the phosphorus as being an impurity—that is, as a constituent of the nuclein or lecithin which is associated with the vitellin. The most recent analyses seem to demonstrate that phosphorus does not exist in vitellin. It is altogether probable that several substances are included under the name “vitellin.”

### PROTEOSES AND PEPTONES.

The members of these two groups will be discussed in connection with the gastric and intestinal digestion of proteids.

### COAGULATED PROTEIDS.

Under this title are included Fibrin, Myosin, and Casein, which are discussed in connection with Fibrinogen, Myosinogen, and Caseinogen, together with such others as are produced by the action of heat on proteids.

### POISONOUS PROTEIDS.

That poisonous proteids of both vegetable and animal origin exist has been abundantly demonstrated. Among those of *vegetable* origin are the following: *Abrin*, a compound of a globulin and a proteose, obtained from the seeds of jequirity, *Abrus precatorius*; *papain*, or a proteid associated with it, obtained from the fruit of the papaw-tree, *Carica papaya*; *ricin*, from the seeds of castor-oil, *Ricinus communis*; and *lupino-toxin*, from *Lupinus luteum*.

The number of poisonous proteids of animal origin is not inconsiderable, of which may be mentioned: *Snake-poison*; proteids from the *serum of some eels*, those from some *spiders*, and the stinging apparatus of some *insects*; *ordinary peptones and proteoses*, as is shown by the fact that 0.3 gram of commercial peptone per kilogram of body-weight will kill a dog when injected into its blood; some *nucleoproteids*, as Wooldridge's tissue fibrinogens, which cause the blood to coagulate in the vessels when



injected into them ; and various proteids produced by *bacteria*, the so-called *toxalbumoses*.

The two classes of these poisonous proteids which demand more than a passing notice are snake-poison and the bacterial poisons.

**Snake-poison.**—The first snake-poison isolated was *viperin* from an adder. Subsequently *crotalin* was obtained from the venom of a rattlesnake, and its albuminous nature was recognized ; and later the venom of the cobra and other poisonous snakes was studied. It has been demonstrated that in the venom of the Australian black snake there are three proteids : One, a non-virulent albumin, and the two others, which are virulent, are proto- and heteroproteose. The poison produces intravascular coagulation of the blood, probably by causing a disintegration of the cells of the endothelium of the vessels or of the red corpuscles, thereby producing or setting free a nucleoproteid. In discussing this subject, Halliburton, in Schäfer's *Physiology*, to which we are indebted for this *résumé* of proteids or poisons, says that with regard to the question how these poisonous proteoses are formed, C. J. Martin puts forward the following hypothesis : The cells of the venom-gland exercise a hydrolyzing (p. 119) agency on the albumin supplied them by the blood, the results of which influence are the poisonous proteoses found in the venom. A difference between the process and digestion by pepsin, or by anthrax bacilli, is that the hydration stops short at the proteose stage, and is not continued so as to form peptone, or simple nitrogenous materials, like leucin, tyrosin, or alkaloids. Gland epithelium is certainly capable of exercising such a hydrolyzing influence ; the conversion of glycogen into sugar in the liver-cells is one of the best known examples. The following table is given illustrating the analogy between various hydrolyzing processes, proteid being in all cases the material acted on :

Primary Agents.	Ferment.	Products.	
		Albuminous.	Nitrogenous but not Albuminous.
1. Epithelial cell of gastric gland.	Pepsin.	Proteoses, peptone.	Brieger's peptotoxin, a very doubtful basic substance.
2. Epithelial cell of pancreas.	Trypsin.	Proteoses, peptone.	Leucin, tyrosin, lysin, arginin, aspartic acid, ammonia.
3. <i>Bacillus anthracis</i> .	None yet found.	Proteoses, peptone.	Leucin, tyrosin, and an anthrax alkaloid.
4. <i>Bacillus diphtheriæ</i> .	Ferment not named.	Proteoses.	Organic acid of doubtful nature.
5. Epithelial cell of snake's venom-gland.	None yet found.	Proteoses.	Trace of organic acid.

It has been ascertained that 0.00025 gram of the venom of *Hoplocephalus custus*, an Australian snake, will kill a rabbit weighing a kilogram ; this is about the same virulence as the toxin of diphtheria.

**Bacterial Poisons.**—Halliburton says that the word *ptomain* was originally employed to designate those putrefaction-prod-

ucts of animal substances which give the reactions of vegetable alkaloids, and which are more or less poisonous. The similar substances formed by metabolic activity, either from lecithin or proteids, are called *leukomains*. One of these alkaloids, *tyrotoxin*, has been obtained from putrid cheese; another, *mytilotoxin*, from muscles, and there are others. Brieger obtained poisonous alkaloids, which he called toxins, from cases of typhoid fever and tetanus, calling that from the former *typhotoxin* and the latter *tetanin*.

From this brief consideration of the subject it will be seen that both ptomains and toxalbumoses may be produced by bacteria.

### ALBUMINOIDS.

The term albuminoids implies that the members of this class resemble albumin; indeed, they bear a resemblance to all the proteids, but also differ from them in important particulars. The members of the class are: Collagen, Gelatin, Elastin, Reticulin, Keratin, Neurokeratin, Mucin, and Nuclein.

**Collagen.**—This is the substance in the white fibers of connective tissue which produces gelatin. In bones it exists under the name of *ossein*, associated with some other organic substances. There exists in hyaline cartilage a substance which has long borne the name of *chondrigen*, which when boiled was said to produce *chondrin*, but it is now known that “chondrigen” is a mixture of collagen and mucin or mucinoid substances.

Collagen is insoluble in water, dilute acids, and alkalies. When treated with boiling water or with pepsin and hydrochloric acid it becomes *gelatin*. It is considered to be the anhydrid of gelatin, as is expressed by the following equation:



It should be said, however, that these formulæ have not been definitely established. Indeed, another formula has been given for gelatin by an equally competent chemist:  $\text{C}_{76}\text{H}_{124}\text{N}_{34}\text{O}_{29}$ . In neither of these formulæ does sulphur occur; when it has been found on analysis it has been regarded by some as an impurity, while one authority, at least, believes it to be an integral part of both collagen and gelatin to the amount of 0.6 per cent.

**Gelatin.**—Gelatin is insoluble in cold but soluble in hot water; and when the solution cools it gelatinizes or forms a jelly. It reacts with Millon's reagent, and with copper sulphate and caustic potash it gives a violet color. Tannic acid precipitates it, and upon this depends the process of tanning. It is levorotatory, the amount of rotation being about  $-130^\circ$ . If gelatin is boiled for twenty-four hours, its power to gelatinize is lost, and it becomes



gelatin-peptone. When acted on by pepsin and hydrochloric acid, as during gastric digestion, it becomes protogelatose, then deuterogelatose, and lastly gelatin-peptone. A similar set of changes results from the action of the trypsin of the pancreatic juice.

Gelatin is a "proteid-sparing" substance—that is to say, that while it cannot take the place of the proteids as a tissue-former, its nitrogen not being available for that purpose, yet it does serve a useful purpose as food. When gelatin is used as food to replace entirely the proteids, the animals experimented upon starve to death. The gelatoses and gelatin-peptones which result from its digestion are oxidized, as are carbohydrates and fats, producing  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ , and probably urea. It is a source of energy, therefore, and in so far as it fulfils this office it takes the place of proteids, even though, unlike them, it cannot supply the waste of nitrogenous tissues. It "spares" the proteids more than do carbohydrates, and still more than fats. Thus proteids serve in the economy a double purpose: (1) as tissue-formers and (2) as sources of energy. It is in this latter regard that gelatin can replace the proteids. It has been found, however, that when gelatin is given to replace proteids the amount given must be twice that which it is designed to replace; practically it has been shown that one-fifth the amount of proteid may be thus replaced.

**Elastin.**—From the yellow fibers of connective tissue is obtained this member of the albuminoid class. It has the following approximate percentage-composition: C, 54.24; H, 7.27; N, 16.7; O, 21.69; S, 0.3. Some authorities regard the sulphur as an impurity. Elastin, like collagen, but less easily, is changed by hydrochloric acid and pepsin, and also by trypsin, the products being proto-elastose and deuterio-elastose; but unlike collagen the change goes no further—that is, no peptone is formed in either case.

**Reticulin.**—Retiform or reticular tissue, such as occurs in lymphatic glands, is in many respects so similar to ordinary areolar tissue that so eminent an authority as Schäfer regards the former simply as a variety of connective tissue; but others claim that while there are no histologic points of difference, yet from a chemical standpoint there is a marked difference, and this consists in the presence in the fibers of *reticulin*, whose percentage-composition is C, 52.88; H, 6.97; N, 15.63; S, 1.88; P, 0.34; ash, 2.27. The absence of glutaminic acid among the decomposition-products of reticulin, while it is present in those of collagen and gelatin, is one of the points relied upon to establish the difference between the two tissues.

In discussing this subject Halliburton says: "We are, therefore, confronted with the difficulty that the fibers of reticular tissue are anatomically continuous with and histologically identical

with the white fibers of connective tissue, and yet they contain chemically this new material. The answer to the problem is probably that reticulin is not specially characteristic of reticular fibers, but is present in all white connective-tissue fibers."

**Keratin.**—This substance is found in all horny tissues, such as hair, nails, and epidermis. It is soluble in water at 150°–200° C., and in alkalies, but is unaffected by pepsin or trypsin, and contains a large amount of sulphur. Its percentage-composition in hair is as follows: C, 50.60; H, 6.36; N, 17.14; O, 20.85; S, 5. In the skin the change of the protoplasm of the cells into keratin takes place in two strata which are between the Malpighian layer and the horny layer—the *stratum lucidum*, next to the horny layer, and the *stratum granulosum*, next to the Malpighian. In the latter the cells contain *eleidin*, which is regarded as an intermediate stage in the conversion of the protoplasm into keratin.

**Neurokeratin.**—A modified form of keratin, neurokeratin, occurs in the medullary sheath of nerves and in neuroglia. Its percentage composition varies considerably, being in some portions of the nervous system as low as 0.3, and in others as high as 2.9.

**Mucins.**—Inasmuch as mucin is not a single substance, but consists rather of several varieties, differing in solubility in acid and alkaline solutions, it is more correct to speak in the plural. Mucin is an ingredient of mucus, the product of mucous glands, and it exists also in the ground-substance of connective tissue. Mucins give the characteristic viscosity to the fluids in which they occur; they are soluble in alkalies, and, when so dissolved, can be precipitated by acetic acid. When they are treated with superheated steam a carbohydrate called animal gum is split off, the formula of which is  $C_6H_{10}O_5$ . When this latter is treated with a dilute mineral acid it is changed into a reducing but not fermentable sugar, whose formula is  $C_6H_{12}O_6$ . It is an interesting fact that from other albuminoids, and also from proteids, carbohydrates may be obtained. The percentage-composition of submaxillary mucin is: C, 48.84; H, 6.80; N, 12.32; O, 31.20; S, 0.84.

**Nuclein.**—This substance has been sufficiently discussed in connection with the nucleoproteids (p. 111).

## ENZYMES.

There are two varieties of ferments: (1) organized ferments, of which yeast is an example, and (2) unorganized or soluble ferments, of which pepsin is an example. It has been proposed to limit the term *ferment* to the *organized* class, and to denominate the changes which its members cause in substances upon which they act as *fermentation*, and to the soluble or *unorganized* class

to apply the name of *enzyme*, and to apply to the process for which its members are responsible the term *zymolysis*.

The distinction between the organized and unorganized ferments is, after all, probably a superficial and not a fundamental one. The fermentative or zymolytic action is in both cases due to a substance which cells produce. In the one case, that of an organized ferment, such as yeast, this product is thrown out by the cells of the yeast-plant while they are in contact with the substance acted upon—dextrose, for example. In the case of an unorganized ferment or enzyme—trypsin, for instance—the cells of the pancreas which produce it remain in the organ, while the product is poured out with the other constituents of the secretion and brings about its action on the proteids at a distance from the cells. In both instances it is the product of cells which produces the change. There will here be discussed only the unorganized ferments or enzymes.

Some of the enzymes on analysis have been found to be very similar in their composition to the proteids, but the consensus of opinion is that they are not proteids, notwithstanding this resemblance. The failure to determine their exact composition is due to the fact that as yet no enzyme has been obtained pure and free from proteids; and also because the quantity is, in any event, exceedingly small. Like most proteids they are not diffusible, and cannot therefore be separated from them by dialysis.

Enzymes are soluble in water, and are precipitated by an excess of absolute alcohol or by saturation with ammonium sulphate. They are changed by alcohol only when the contact has existed for a considerable time; this period is, however, shorter in the case of pepsin than in that of the other enzymes.

Minute quantities of enzymes under proper conditions will bring about zymolytic changes in considerable quantities of the substances upon which they act, apparently without suffering any diminution. Thus, 1 part of rennin will coagulate 800,000 parts of milk, and pepsin will dissolve in seven hours 500,000 times its weight of fibrin. The conditions under which they act vary for each enzyme; but, as a rule, high temperatures destroy and low temperatures inhibit, while for each there is a temperature at which its action is the most pronounced; this is called the "optimum" temperature. Thus for pepsin the optimum temperature is from 35° to 40° C., while below 1° C. its action ceases, as it does also at 70° C., while boiling permanently destroys it. It has been determined, however, that when perfectly dry the enzymes may be heated to 160° C. without destroying their power.

An interesting fact also connected with the enzymes is, that when they have produced a considerable amount of their product their action is diminished, and that if this new product accumulates still more, the zymolytic action of the enzymes may be

brought to an end, although their power to act would still be present if these products were removed. In some instances the enzyme is not the direct product of the cells, but the cells form what is termed a *zymogen*, which is afterward converted into the enzyme. Each zymogen is named from the enzyme which it produces: thus the zymogen of trypsin is *trypsinogen*, that of pepsin is *pepsinogen*, etc. It is an interesting and valuable fact that chloroform inhibits the action of the organized ferments, but does not interfere with that of the enzymes.

As it is very important to have a clear idea of the meaning of certain terms which occur repeatedly in the discussion of the enzymes and their action, these terms will here be defined, namely:

**Amylolytic Enzyme.**—The conversion of amyloses into sugar is an *amylolytic* change, and an enzyme which has the power of producing this change is an amylolytic enzyme; such are ptyalin of the saliva and amylopsin of the pancreatic juice.

**Diastatic or Diastasic Enzyme.**—There exists in barley an enzyme, diastase, which has the power of changing starch into sugar; the change itself, and also the enzyme, are spoken of as *diastatic* or *diastasic*. It will be seen, therefore, that amylolytic, diastatic, and diastasic are synonymous.

**Proteolytic Enzyme.**—The conversion of proteids into proteoses and peptones is a *proteolytic* change, and an enzyme which causes it is a proteolytic enzyme; such are pepsin of the gastric juice, and trypsin of the pancreatic juice.

**Steatolytic Enzyme.**—The splitting of fats into fatty acids and glycerin is a *steatolytic* process, and an enzyme which has this power is a steatolytic enzyme; such is steapsin or lipase of the pancreatic juice. These enzymes are also termed *lipolytic* and *adipolytic*.

**Sugar-splitting Enzymes.**—These enzymes split up sugar; thus, invertin or invertase splits cane-sugar into glucose and levulose or fructose, this product being known as invert-sugar (p. 92); lactase splits up lactose or milk-sugar into glucose and galactose; glucase hydrolyses maltose into glucose.

**Coagulating Enzymes.**—These enzymes change soluble into insoluble proteids; such are rennin, fibrin-ferment, and myosin-ferment.

**Activating Enzymes.**—In the intestinal juice, produced by the intestinal epithelium, there is an enzyme which “activates” trypsinogen—*i. e.*, changes the trypsinogen into the active trypsin; this enzyme is called *enterokinase*. In general, enzymes which have the power of activating zymogens are called *kinases*.

**Hydrolysis.**—It is now generally accepted that in many of these various conversions the change consists in the assumption of a molecule of water; thus,



This change is called *hydrolysis*, and the action is said to be *hydrolytic*. Chemistry has established this fact for amylolytic and inversive enzymes, and it is probably equally true for those that are proteolytic. For the action of all enzymes the presence of water is essential.

The consideration of the individual enzymes will be deferred until the action of the various fluids in which they occur is discussed.

### METABOLISM.

The human body is during life the seat of constant activity, during which almost limitless chemical changes take place. These are collectively spoken of under the term *metabolism*. Some of these are concerned with the upbuilding of the body, and are termed *anabolic*; while others result in the wasting of the tissues, and are denominated *katabolic*. Anabolism and assimilation may be regarded as synonymous terms, while katabolism and destructive assimilation express somewhat the same idea. The word metabolism has been defined as "the process by which living cells or organisms are capable of incorporating substances obtained from food into an integral part of their own bodies; the changes that proteids and other constituent substances undergo in the body. It is *constructive* when the substance becomes more complex; *destructive* or *retrograde* when it becomes simpler by the change." Still another lexicographer defines metabolism as "The act or process by which, on the one hand, the dead food is built up into living matter, and by which, on the other, the living matter is broken down into simple products within a cell or organism; the sum of the anabolic or constructive (assimilation) and the katabolic or destructive (decomposition) processes." If the anabolic and katabolic processes should exactly balance one another, the body would be in a state of *equilibrium*, but this never occurs absolutely.

As a result of the destructive changes which take place in the body it is essential that they be counterbalanced so far as is possible, and this is accomplished by taking into the body food and oxygen. If an individual is deprived of oxygen, death occurs in a few minutes from asphyxia. No less certainly does death supervene if he is deprived of food, although the time required to bring about the result is much greater, depending considerably upon the circumstances and upon the age of the individual. In the instance frequently quoted, when, in the year 1816, one hundred and fifty persons were wrecked on the "Medusa," all but fifteen were dead after having been without food, either solid or liquid, for thirteen days. In this instance, however, it must be borne in mind that the exposure incident to the shipwreck probably contributed to hasten the fatal result. It may be said, in general, that death will supervene when the body has lost four-

tenths of its weight. When death thus occurs from starvation the various tissues lose different amounts proportionately. The following table gives the loss in percentage :

Bone . . . . .	5.4	Testes . . . . .	0.1
Muscle . . . . .	42.2	Intestine . . . . .	2.0
Liver . . . . .	4.8	Brain and cord . . . . .	0.1
Kidneys . . . . .	0.6	Skin and hair . . . . .	8.8
Spleen . . . . .	0.6	Fat . . . . .	26.2
Pancreas . . . . .	0.1	Blood . . . . .	3.7
Lungs . . . . .	0.3	Other parts . . . . .	5.0
Heart . . . . .	0.0		

From this table it will be seen that the greatest loss takes place in the muscles and fat.

### FOOD.

Food may be defined as *material taken into the body to build up its tissues and repair their waste, or to produce energy*. In the discussion of the effects of alcohol other definitions are given (p. 158). Foods are made up of food-stuffs and other substances associated with them, which latter, being indigestible, are of no value either for purposes of nutrition or for the generation of energy.

*Food-stuffs* are divided into four classes, which have already been somewhat discussed in treating of the physiologic ingredients. The classes of food-stuffs are: Inorganic, including water and salts; Carbohydrates; Fats or oils; Proteids.

**Inorganic Food-stuffs.**—**Water** is, as has been pointed out, one of the most important ingredients of the body, and is therefore one of the most essential of the food-stuffs. It is the solvent of many of the constituents of the food and the salts, and by its softening action aids in the processes by which the hard portions of food are masticated and swallowed. It should be taken in quantities much larger than is customary. The prevalent idea that water is harmful when taken with food because of its action in diminishing the secretion of gastric juice, is entirely erroneous. On the contrary, water, even when cold, stimulates the gastric glands, and more of their secretion is formed. To this we shall recur in discussing the process of gastric digestion. Nor is it true that water is “fattening,” in the sense that those who drink large quantities necessarily become obese. If fat is “taken on” by such persons, it is only because of the indirect influence which water exerts in keeping the nutritive processes up to a higher standard and thus increasing assimilation and leaving a balance to be stored up as fat. The source of the fat is not the water, but the carbohydrates and other food-stuffs which are convertible into fat.

Water being thus important—indeed, essential—great care should be taken to have it free from harmful ingredients. These may be inorganic and organic.



The objectionable *inorganic* constituents are those which give to the water its "hardness." These are calcium carbonate, to which "temporary" hardness is due, and calcium chlorid and sulphate, and salts of magnesium, which account for "permanent" hardness. Water is not considered to be "hard" unless it contains more than ten grains of calcium carbonate or its equivalent per gallon (6.479 decigrams per 3.785 liters). Rain-water contains less than half a grain (32.395 milligrams). To hard water gastric and intestinal derangements are doubtless attributable, but the evidence that vesical calculi or goiter are produced by it is far from convincing.

It is, however, to the *organic* impurities which drinking-water not infrequently contains that especial attention should be directed, and more particularly to those in the form of disease-germs. These organisms are the undoubted cause of cholera and typhoid fever, and most probably of a form of dysentery called "amebic" or "tropical." Each of these diseases is produced by its own specific organism; thus, that which produces cholera is *Spirillum cholerae Asiaticæ*; that of typhoid fever, *Bacillus typhosus*; and that of tropical dysentery, *Amæba dysentericæ*. These germs are contained in the stools of persons suffering from these diseases, and their stools not being disinfected, the germs gain access to drinking-water either by a leaking privy-vault or in some other way, and those who drink such water are liable to become infected. Many instances of epidemics thus caused could be cited, but one must suffice. One of the most striking epidemics of typhoid fever was that which occurred in Plymouth, Pa., in 1885. The population was between 8000 and 9000. Of this number, 1153 contracted the fever, and 114 of these died. A careful investigation showed that the water-supply of this mining-town had become infected by the stools of a single case of typhoid fever. These stools, in an undisinfected condition, had been deposited on the ground during the winter, and it was not until spring, when the snow melted and warm showers occurred, that these infected dejecta were washed into the water-supply. The first case occurred within two or three weeks after. This instance demonstrates not only the infecting power of a single case of disease, but also the resisting power which the typhoid bacillus possesses against cold, for these stools had been frozen for several months. Indeed, from laboratory experiments we know that the *Bacillus typhosus* retains its vitality even after having been frozen for one hundred and three days.

The resistance of many other bacteria to low temperatures is a well-established fact. The cholera germ is not killed at  $-32^{\circ}$  C. (Koch). The bacillus of tuberculosis retains its vitality after an exposure of forty-two days to the temperature of liquid air,  $-193^{\circ}$  C. (Swithinbank). *Bacillus coli* and other bacteria are not killed after an exposure of ten hours to the temperature of liquid hydrogen,  $-252^{\circ}$  C. (McFadyen and Rowland).

But, while infection is not destroyed by freezing, it is by boiling, and there is no surer way of destroying the germs which water may contain than by boiling it for half an hour. Boiled water is not as unpalatable as is generally supposed. Even if it was, unpalatability is less objectionable than infection, and in all doubtful cases water should be boiled.

Another lesson to be learned from this epidemic and from the laboratory experiments referred to is that ice may be a source of infection as well as water, and even though the water is boiled this will be of no avail if infected ice is used to cool it. In ice which was suspected of having caused typhoid fever at the St. Lawrence State Hospital, on the St. Lawrence River, Hutchings and Wheeler found typhoid bacilli.

The writer investigated an epidemic of dysentery in which the disease was traced to ice used in drinking-water. The ice had been cut from a pond in which during the summer hogs wallowed, and in which they deposited their excreta. When melted this ice had a most offensive odor. Other instances might be given showing the danger from the use of impure ice, but the one cited will suffice. Fortunately, there is now furnished for use in many of our cities artificial ice, which, if properly prepared, is free from all contamination. In this process of manufacturing ice the water is not only boiled, but is distilled, and when ready for freezing is absolutely pure. But even this ice is not always what it claims to be. Unscrupulous dealers will often supply river ice when they are supposed to deliver the artificial product, and manufacturers of the latter are sometimes careless. With boiled water and properly manufactured artificial ice, all danger of infection through these channels will surely be prevented.

**Salts.**—The list of salts taken in with the food has already been given, the most important being sodium chlorid, calcium phosphate, and the alkaline carbonates and phosphates. The offices which these salts perform in the economy of the body vary. By some of them the solubility of certain ingredients is made possible, such as the globulin of the blood by virtue of the presence of sodium chlorid. From the chlorids the hydrochloric acid of the gastric juice is produced. Salts are stimulants also to the glands, causing the latter to secrete more actively; thus the digestive fluids are more abundantly poured out when the food is properly salted, and the kidneys more completely perform their functions under the stimulation of the salts. If salts are removed from the food of a pigeon, it will die in three weeks; the same deprivation of salts in the case of a dog will cause its death in six weeks.

**Carbohydrates.**—These food-stuffs, in the form of starch and sugar, are especially abundant in vegetable foods. They are present also in milk, but less so in other animal foods.

Cane-sugar is an article of diet which is used to an enormous



extent throughout the world. For an exceedingly interesting and valuable contribution to the literature of this subject the reader is referred to Farmers' Bulletin, No. 93, issued by the United States Department of Agriculture, entitled "Sugar as Food," by Mary Hinman Abel. From this we have derived much information.

Between seven and eight million tons of cane-sugar are used annually in the different countries of the world; England consuming in 1895, 86 pounds per capita; the United States, 64 pounds; while Italy, Greece, and Turkey consumed less than 7 pounds. About two-thirds of the crystallized sugar now used is derived from the sugar-beet, which has become so developed that while the beet of 1806 contained but 6 per cent. of sugar, that of to-day contains 15 per cent.

The following table gives the average composition of raw sugar from different sources:

*Average Composition of Raw Sugar.*

Sources from which obtained.	Water.	Cane-sugar.	Other organic substances.	Ash.
	Per cent.	Per cent.	Per cent.	Per cent.
Sugar-cane . . . . .	2.16	93.33	4.24	1.27
Sugar-beet . . . . .	2.90	92.90	2.59	2.56
Sorghum . . . . .	1.71	93.05	4.55	0.68
Maize . . . . .	2.50	88.42	7.62	1.47
Palm . . . . .	1.86	87.97	9.65	0.50
Maple . . . . .	. . . . .	82.80		

The cane-sugar obtained from these sources is identical, and the popular opinion that beet-sugar is not as sweetening and not as good a preservative as that derived from the cane is erroneous. It is a satisfaction to know that the cane-sugar of commerce is as pure as is possible; of five hundred samples examined by the United States Government chemists, not one was adulterated.

The value of sugar as food has been abundantly demonstrated; its office being to furnish energy to the body in the form of heat and muscular work, in which process it undergoes oxidation and becomes converted into  $\text{CO}_2$  and  $\text{H}_2\text{O}$  (p. 257). Experiments conducted in Berlin and elsewhere show that sugar is "well adapted to help men to perform extraordinary muscular labor;" and it has been used in the German army with such excellent results in appeasing hunger, mitigating thirst, and preventing exhaustion, that an increase of the sugar ration to sixty grams a day has been recommended.

The general conclusions drawn by Abel in the bulletin above referred to are as follows:

"One may say in general that the wholesomeness of sweetened foods and their utilization by the system are largely a question of quantity and concentration. For instance, a simple pudding

flavored with sugar rather than heavily sweetened is considered easy of digestion ; but when more sugar is used, with the addition of eggs and fat, we have, as the result, highly concentrated forms of food which can be utilized by the system only in moderate quantities and which are always forbidden to children and invalids.

“It is true that the harvester, lumberman, and others who do hard work in the open air consume great amounts of food containing considerable quantities of sugar, such as pie and doughnuts, and apparently with impunity ; but it is equally true that people living an indoor life find that undue amounts of pie, cake, and pudding, with highly sweetened preserved fruit, and sugar in large amounts on cooked cereals, bring indigestion sooner or later.

“From a gastronomic point of view it would seem also that in the American cuisine sugar is used with too many kinds of food, with a consequent loss in variety and piquancy of flavor in the different dishes. The nutty flavor of grains and the natural taste of wild fruits is concealed by the addition of large quantities of sugar.

“In the diet of the under-nourished large amounts of sugar would doubtless help to full nutrition. This point is often urged by European hygienists. In the food of the well-to-do it is often the case, however, that starch is not diminished in proportion as sugar is added. That sugar on account of its agreeable flavor is a temptation to take more carbohydrate food than the system needs cannot be denied. The vigor of digestion in each particular case would seem to suggest the limit. A lump of sugar represents about as much nutriment as an ounce of potato, but while the potato will be eaten only because hunger prompts, the sugar, because of its taste, may be taken when the appetite has been fully satisfied.

“Sugar is a useful and valuable food. It must, however, be remembered that it is a concentrated food, and therefore should be eaten in moderate quantities. Further, like other concentrated foods, sugar seems best fitted for assimilation by the body when supplied with other materials which dilute it or give it the necessary bulk.

“Persons of active habit and good digestion will add sugar to their food almost at pleasure without inconvenience, while those of sedentary life, of delicate digestion, or of a tendency to corpulency would do better to use sugar very moderately. It is generally assumed that four or five ounces of sugar per day are as much as it is well for the average adult to eat under ordinary conditions.”

**Fats or Oils.**—These food-stuffs are found in milk, in butter, in cheese, in the fatty tissues of meat, and also in some vegetables, such as nuts. The following table shows the amount in some of the ordinary foods :

Meat . . . . .	5 to 10 per cent.
Milk . . . . .	3 to 4 " "
Eggs . . . . .	12 " "
Cheese . . . . .	8 to 30 " "
Butter . . . . .	85 to 90 " "

**Proteids.**—This class contains some of the most valuable of the food-stuffs. The importance of the class is readily understood when it is recalled that the principal ingredients of the blood and the muscles are supplied by the proteids of the food. This is the only class whose members contain nitrogen, and it has therefore been sometimes spoken of as the “nitrogenous” class. The albuminoids contain nitrogen also, but this class has little nutritive value, except gelatin, which is valuable, but, as has already been stated, its nitrogen is not available for tissue-forming. The proteids are represented in eggs by albumin, in milk by casein, in meat by myosin, in peas and in beans by legumin, and in the cereals by gluten. The amount of proteids varies in different foods; thus there is in

Meat . . . . .	15 to 23 per cent.
Milk . . . . .	3 to 4 " "
Peas and beans . . . . .	23 to 27 " "
Grains (flour) . . . . .	8 to 11 " "
Bread . . . . .	6 to 9 " "
Potato . . . . .	1 to 4 " "

The following diagram (Fig. 85) shows the amount of the principal food-stuffs in some of the more generally used foods :

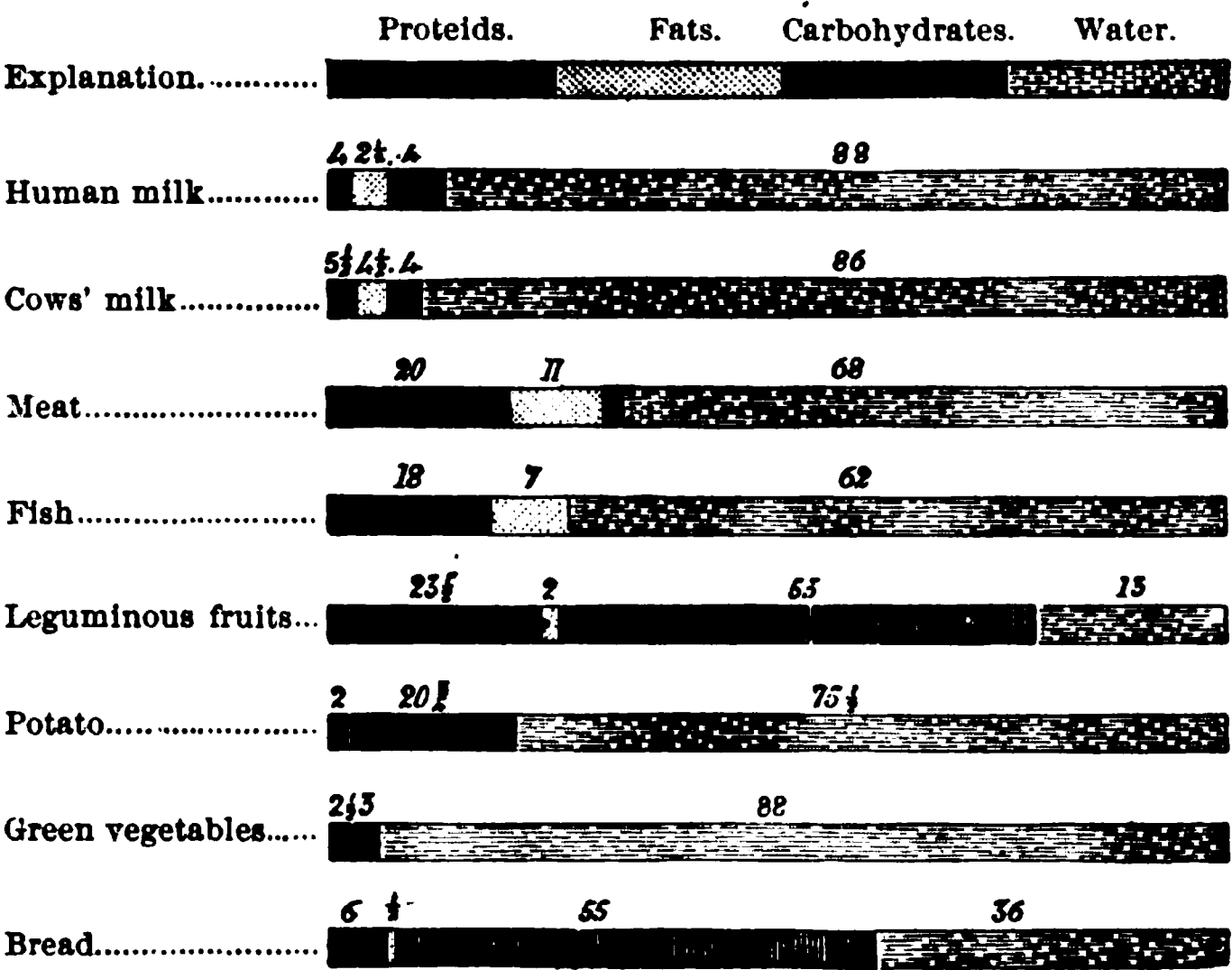


FIG. 85.—Diagram showing proportion of the principal food-stuffs in a few typical comestibles. The numbers indicate percentages. Salts and indigestible materials omitted (after Yeo).

From the above consideration of the food-stuffs it is seen that they are in most respects the same as the tissues of the body ; yet it would be erroneous to infer that the fats and the proteids of the food go directly into the tissues as such, and take the place of the fats and the proteids which are wasted. There are many intermediate steps, some of which are known and will be discussed, and others of which we are entirely ignorant. Experience has abundantly demonstrated that in order to maintain the body at its physiologic standard representatives from all these four classes of food-stuffs must be supplied. If man is deprived of water, death speedily results ; it comes as surely, though not so quickly, if fats or carbohydrates or proteids are cut off from the food-supply. Indeed, a man may be starved to death by withholding the salts.

Whenever, therefore, it is found that life can be maintained physiologically for a long period of time on any diet, it is certain that this diet contains representatives of all the classes enumerated. Thus, milk, which is the sole food of young children—among some of the Eskimos to the sixth year of life—is found on analysis to contain such representatives ; the inorganic class being represented by water and salts, the carbohydrates by milk-sugar, the fats by butter, and the proteids by caseinogen, lactalbumin, and lactoglobulin. It is not, however, sufficient that each class should be represented, but the proportions of the ingredients must be proper. It is possible that any given food may have the requisite constituents, but may have too much of one and too little of another. It has been determined that the daily waste of the body is 250 to 280 grams of carbon and 15 to 18 grams of nitrogen, or about 16 to 1. The carbon given off is principally in the form of carbonic acid in the expired air, while the urea of the urine contains most of the nitrogen eliminated. To supply the waste of the body, then, the proportion in the food of carbon to nitrogen should be as 16 to 1.

In proteids, however, the proportion is 3.5 to 1, so that should proteids only be supplied to the body there would have to be given an enormous amount of nitrogenous food in order to supply enough of the carbonaceous. The effect of this excess of nitrogenous food would be to injure the digestive and eliminating organs. So that to make up this deficiency of carbon, carbohydrates and fats are used in connection with the proteids. Imagine, for instance, the effect upon the digestive apparatus if man's exclusive diet was potatoes. It will be seen by the table that in potatoes there are 2 per cent. of proteids and 20.75 per cent. of carbohydrates. Therefore, to obtain enough proteids from potatoes to sustain life it would be necessary to eat daily at least 3.37 kilograms, or twenty-five good-sized potatoes. In some parts of the world this has been put into practice, the effect being to distend the stomach and to derange digestion to a harmful degree.

And yet we must acknowledge that human life is sustained for

years on a diet which is far from the standard here set forth. Thus the Chinaman, to obtain the nitrogen necessary, must eat about 2000 grams of rice. This gives him about 20 grams of nitrogen, but 700 of carbon. Oatmeal contains carbon and nitrogen in the proportion of 15 to 1.

If the diet was exclusively of meat, then in order to supply the body with the necessary amount of carbonaceous material a very large quantity of meat would be required, and to meet this requirement there would be taken in an excess of nitrogenous constituents, thus placing a serious burden on the eliminating organs to get rid of them. Experience demonstrates that a mixture of foods is the true physiologic method of supplying the wants of the human body; from meat are obtained the proteids necessary for nutrition; from the potato is derived the starch; and from butter is secured the fat. Experience shows also that a higher standard of efficiency is maintained by a variety of food, a change being made from one kind of meat to another and from one vegetable to another, always, however, giving the body the food-stuffs in the proper quantities to supply its demands.

There are individuals who believe that meat-eating is not only unnecessary to, but that it tends also to degrade man; they consequently confine themselves to vegetable diet: this exclusive dietary practice is called "vegetarianism." The vegetarian movement has become widespread both in this country and abroad, and societies with large followings have been formed for its propagation and encouragement. The grounds advanced by its adherents for its support are many. Among them are the following: That the character of the human teeth is not that of a carnivorous, but that of a vegetable and fruit-eating animal; that the same is true of the intestine, that of man resembling very much the intestine of certain fruit-eating apes; that there is in a vegetable and fruit diet all that man needs for his sustenance and well-being, and in a more compact and available form; that many diseases which attack man, such as trichinosis, tuberculosis, tapeworm, etc., would be abolished or at least greatly lessened if meat was not eaten. Other arguments relating to man's physical and moral nature are adduced in favor of vegetarianism.

The following extract from a letter of Dr. Alanus, a vegetarian, published in the *Medical and Surgical Reporter*, gives his experience and also his opinion of vegetarianism:

"Having lived for a long time as a vegetarian without feeling any better or worse than formerly with mixed food, I made one day the disagreeable discovery that my arteries began to show signs of atheromatous degeneration. Particularly in the temporal and radial arteries this morbid process was unmistakable. Being still under forty, I could not interpret this symptom as a manifestation of old age, and being, furthermore, not addicted to drink, I was utterly unable to explain the matter. I turned it over and

over in my mind without finding a solution of the enigma. I, however, found the explanation quite accidentally in a work of that excellent physician, Dr. E. Monin, of Paris. The following is the verbal translation of the passage in question: 'In order to continue the criticism of vegetarianism we must not ignore the work of the late lamented Gubler on the influence of a vegetable diet on the chalky degeneration of the arteries. Vegetable food, richer in mineral salts than that of animal origin, introduces more mineral salts into the blood. Raymond has observed numerous cases of atheroma in a monastery of vegetarian friars, amongst others that of the prior, a man scarcely thirty-two years old, whose arteries were already considerably indurated. The naval surgeon, Treille, has seen numerous cases of atheromatous degeneration in Bombay and Calcutta, where many people live exclusively on rice. A vegetable diet, therefore, ruins the blood-vessels and makes one prematurely old, if it is true that a man is as old as his arteries. It must produce at the same time tartar, the senile arch of the cornea, and phosphaturia.' Having, unfortunately, seen these newest results of medical investigation confirmed by my own case, I have, as a matter of course, returned to a mixed diet. I can no longer consider purely vegetable food as the normal diet of man, but only as a curative method which is of the greatest service in various morbid states. Some patients may follow this diet for weeks and months, but it is not adapted for everybody's continued use. It is the same as with the starvation cure, which cures some patients, but is not fit to be used continually by the healthy. I have become richer by one experience, which has shown me that a single brutal fact can knock down the most beautiful theoretic structure."

Dr. Estes, a distinguished American surgeon, gives it as his experience that vegetarians do not stand the loss of blood well.

In *Farmer's Bulletin*, No. 121, on "Beans, Peas, and other Legumes as Food," issued by the United States Department of Agriculture, the author, Mary Hinman Abel, in comparing vegetable with animal protein, says: "It has been well known that vegetable foods without any help from the animal kingdom will sustain men in health and working power, and careful experiments have shown that protein performs essentially the same part in nutrition, whether it be from milk, meat, cereal, or legume. Among other experiments may be mentioned that of Rutger, a Dutch physician, and his wife, which lasted ten weeks. Their conclusion was that vegetable food can perfectly well be substituted for animal, provided only that it contain the same amount of nutrients in proper proportions. When living on a purely vegetable diet they relied largely on peas, beans, and lentils, eating them in some form at nearly every meal. From an economic standpoint the average difference in the cost of the two kinds of diet was that less fuel was used to cook the animal foods eaten. It is not improbable, however, that there are differences between animal and vegetable



protein that cannot be tested by any method now at our command, differences which would explain the almost universal preference for some animal food in the diet. From our present knowledge it would seem that a mixed diet—of both animal and vegetable food—is the best and most practicable for the vast majority of people.”

In *Physiological Economy in Nutrition*, (p. 139), Prof. Chittenden says, “Man is an omnivorous animal and Nature evidently never intended him to subsist solely on a cereal diet, or on any specific form of food to the exclusion of all others. . . . Vegetarianism may have its virtues, as too great indulgence in flesh foods may have its serious side, but there would seem to be no sound physiological reason for the complete exclusion of any one class of food-stuffs, under ordinary conditions of life.”

From the above consideration of the subject we learn that a proper diet must contain not only the various food-stuffs, but must contain them in the proper proportion. These proportions will vary considerably according to the age of the individual and his occupation, and also according to the climate in which he lives. A glance at the chemical composition of milk, which is the sole food of the infant, shows that the amount of proteids and fats is very much above that in the food of the adult.

Another factor to determine the nutritive value of any food is its digestibility. The chemical analysis of cheese would place it high among the foods, but experience shows that its constitution is such as not readily to permit the action of the digestive fluids, and its availability as a food is therefore low.

The following table represents a daily diet as recommended by two authorities :

	Moleschott.	Ranke.
Proteids . . . . .	120 grams.	100 grams.
Fats . . . . .	90 “	100 “
Carbohydrates . . . . .	333 “	250 “

Ranke’s diet, which he regarded as sufficient for himself, weighing 74 kilos, corresponds to 230 grams of carbon and 14 grams of nitrogen.

While such diets as these are undoubtedly “adequate,” they are, after all, to be regarded as general averages only, to be varied according to the needs of those for whose maintenance provision is to be made. Thus, Voit (p. 138) would supply to a man weighing 70 to 75 kilos, and working ten hours a day, 118 grams of proteid, 56 grams of fat, and 500 grams of carbohydrates: this diet would give him 328 grams of carbon and 18.3 grams of nitrogen, and would have a total fuel-value of 3000 large calories.

Stewart regards 500 grams of bread and 250 grams of lean meat as a fair quantity for a man fit for hard work. To this he adds 500 grams of milk, 75 grams of oatmeal in the form of porridge, 30 grams of butter, 30 grams of fat either in the meat or otherwise, and 450 grams of potatoes. From this would be

obtained 20 grams of nitrogen and 300 grams of carbon, contained in 135 grams of proteid, rather less than 100 grams of fat and somewhat more than 400 grams of carbohydrates. In the form of a table this would appear as follows :

Food.	Quantity in Grams.	Grams of					
		Nitrogen.	Carbon.	Proteids.	Fat.	Carbo- hydrates.	Salts.
Lean Meat . . .	250	8	83	55	8.5	. . . .	4
Bread . . . . .	500	6	112	40	7.5	245	6.5
Milk . . . . .	500	8	35	20	20	25	8.5
Butter . . . . .	30	. . . .	20	. . .	27	. . . .	0.5
Fat . . . . .	30	. . . .	22	. . .	80	. . . .	
Potato . . . . .	450	1.5	47	10	. . .	95	4.5
Oatmeal . . . . .	75	1.7	30	10	4	48	2
		20.2	299	135	97	413	21

The following is the ration of the English soldier :

Bread . . . . .	680 grams.	Sugar . . . . .	37.7 grams.
Meat . . . . .	340 "	Coffee . . . . .	9.4 "
Potatoes . . . . .	453 "	Tea . . . . .	4.6 "
Vegetables . . . . .	226 "	Salt . . . . .	7 "
Milk . . . . .	92 "		

The ration of the German soldier varies considerably from this :

In peace.		In war.	
Bread . . . . .	750 grams.	Bread . . . . .	750 grams.
Meat . . . . .	150 "	Biscuit . . . . .	500 "
Rice . . . . .	50 "	Meat . . . . .	875 "
or Barley groats . . .	120 "	Smoked meat . . . .	250 "
Legumes . . . . .	230 "	or Fat . . . . .	170 "
Potatoes . . . . .	1500 "	Rice . . . . .	125 "
		or Barley groats . . .	125 "
		Legumes . . . . .	250 "

The following tables show the net and approximate gross weights of 1000 rations (and of 1 ration) as usually issued by the United States Subsistence Department:

TABLE I.—The “Emergency” Ration.

1000 Complete Rations.		Net weight.	Approxi- mate gross weight.
		Pounds. 1000	Pounds. 1000
Hard Bread . . . . .		625	625
Bacon . . . . .		250	250
Pea-meal . . . . .		125	125
Coffee, roasted and ground . . . . .		0.58	0.58
Saccharin . . . . .		40	40
Salt . . . . .		2.5	2.5
Pepper, black . . . . .		31.25	31.25
Tobacco, plug . . . . .		. . . .	100
Bags, wrappers, etc. . . . .			
1000 rations . . . . .		2074.33	2174.33
1 ration . . . . .		2.07	2.17



TABLE II.—*The “Field” Ration.*

1000 Complete Rations.	Net weight.	Approximate gross weight.
	Pounds.	Pounds.
Bacon . . . . .	750	883
Hard Bread . . . . .	1000	1125
Beans . . . . .	150	162
Potatoes, Onions, and Canned Tomatoes, when possible .	1000	1158
Coffee, roasted . . . . .	80	92
Sugar . . . . .	150	161
Vinegar . . . . .	80	97
Candles . . . . .	15	17
Soap . . . . .	40	44
Salt . . . . .	40	44
Pepper, black . . . . .	2.5	3
1000 rations . . . . .	3307.5	3786
1 ration . . . . .	3.31	3.79

When flour is issued instead of hard bread, 40 pounds of baking-powder or dry yeast.

TABLE III.—*The “Travel” Ration, used on Journeys by Railroads, Stages, or Steamboats.*

1000 Complete Rations.	Net weight.	Approximate gross weight.
	Pounds.	Pounds.
For first four days:		
Hard Bread . . . . .	1000	1125
Beef, canned . . . . .	750	875
Beans, baked, 3-pound cans . . . . .	450	520
Coffee, roasted . . . . .	80	92
Sugar . . . . .	150	161
1000 rations . . . . .	2430	2773
1 ration . . . . .	2.43	2.77
After fourth day add:		
Tomatoes (gallon cans) . . . . .	1000	1360
1000 rations . . . . .	3430	4133
1 ration . . . . .	3.43	4.13

TABLE IV.—*The “Travel” Ration for Journeys when Liquid Coffee is furnished.*

1000 Complete Rations.	Net weight.	Approximate gross weight.
	Pounds.	Pounds.
Hard Bread . . . . .	1000	1125
Beef, canned . . . . .	750	875
Beans, baked, 3-pound cans . . . . .	450	520
1000 rations . . . . .	2200	2520
1 ration . . . . .	2.2	2.52

Twenty-one cents per ration are allowed for purchase of liquid coffee.

TABLE V.—The “Garrison” Ration, with the usual Proportions of Fresh and Salted Meats and Vegetables.

1000 Complete Rations.	Net weight.	Approximate gross weight.
	Pounds.	Pounds.
Meat :		
Pork, $\frac{1}{10}$ . . . . .	75	125
Bacon, $\frac{1}{10}$ . . . . .	150	177
Fresh Beef, $\frac{7}{10}$ , 875 lbs., or fresh Beef, 750 lbs., and Canned Salmon, 100 lbs. . . . .	875	885
Flour . . . . .	1125	1507
Vegetables :		
Dry—Beans or Peas . . . . .	75	81
Or Rice or Hominy . . . . .	50	54
Fresh—Potatoes, 800 lbs. } or { Potatoes . . . . . 700 lbs. }	800	808
Onions . 200 lbs. } { Canned Tomatoes, 300 lbs. }	300	350
Coffee, green . . . . .	100	122
Sugar . . . . .	150	161
Vinegar . . . . .	80	97
Candles . . . . .	15	17
Soap . . . . .	40	44
Salt . . . . .	40	44
Pepper, black . . . . .	2.5	3
1000 rations . . . . .	3877.5	4475
1 ration . . . . .	3.88	4.48

The table on page 134 shows the chemical composition and nutrient value of these foods.

Until the Spanish-American War the United States had no occasion to provide a ration especially adapted to the soldier in the tropics, and as a result it is conceded that the present ration is inadequate to his needs. A court of inquiry appointed to investigate the character of the food issued to the troops during the war with Spain reported that “it seems to be clearly established that the army ration as supplied, without modification, to the troops serving in the West Indies, was by no means well adapted for use in a tropical climate.”

A most admirable essay on the subject of “The Ideal Ration for an Army in the Tropics,” written by Captain E. L. Munson, Surgeon in the United States Army, and to which was awarded a prize, appeared in the *Journal of the Military Service Institution of the United States* for May, 1900, to which our readers are referred for an excellent and exhaustive consideration of the subject of diet in hot countries. From this essay we desire to make some quotations.

Dr. Munson concludes “that the present United States Army ration is made up of admirably selected articles in more than sufficient variety, and that it is not only wholly unnecessary, but quite inadvisable to consider any nutritive substances outside those articles legally established as components of the food for the United States soldier. He thinks, however, that the proportion in which these are issued should be materially altered. The dietaries which he recommends are given on pages 135 and 136.

Table showing Chemical Composition and Nutrient Values of Various Articles of the Ration of the United States Soldier (Atwater, Byrant, and Munson).

ARTICLES OF RATION.	Quantities per ration, ounces.	Per cent. of					Amounts present in ration (Grams).				Fuel-value per ration, calories.
		Water.	Protein.	Nitrogen.	Fat.	Carbo-hydrates.	Protein.	Nitrogen.	Fat.	Carbo-hydrates.	
Fresh Beef (fore- and hind-quarters) . .	20	50.5	14.7	2.35	15.8	..	83.35	13.3	89.5	..	1180
or Fresh Mutton . .	20	43.8	16.3	2.60	22.2	..	92.40	14.7	125.8	..	1440
or Pork . . . . .	12	16.2	16.2	2.59	66.2	..	55.08	8.8	225.08	..	2187
or Bacon . . . . .	12	16.8	9.2	1.17	61.8	..	31.28	4.99	210.12	..	2085
or Salted Beef . . .	22	49.6	14.2	2.27	22.8	..	88.60	14.16	142.3	..	1534
or Dried Fish (cod) .	14	40.3	16.0	2.56	0.4	..	63.52	10.16	1.59	..	276
or Fresh Fish (cod, whole) . . . .	18	38.7	8.0	1.28	0.2	..	40.8	6.5	1.02	..	155
Flour . . . . .	18	12.8	10.8	1.55	1.1	74.6	55.08	7.9	5.6	380.46	1850
or Soft Bread . . . .	18	35.4	9.5	1.36	1.2	52.8	48.45	6.9	6.12	269.28	1355
or Hard Bread . . . .	16	9.2	14.4	2.30	1.3	72.8	65.70	10.44	5.9	330.5	1712
or Corn-meal . . . . .	20	12.9	8.9	1.41	2.2	75.1	50.40	7.99	12.4	427.8	1986
Beans . . . . .	2½	13.2	22.3	3.56	1.8	59.1	15.16	2.42	1.22	40.18	240
or Rice . . . . .	1½	12.4	7.8	1.24	0.4	79.0	3.50	0.56	0.18	35.55	163
or Peas . . . . .	2½	10.8	24.1	3.85	1.1	61.5	16.38	2.62	0.75	41.8	246
or Hominy . . . . .	1½	11.9	8.2	1.31	.6	78.9	3.69	0.59	0.27	35.5	172
Potatoes . . . . .	16	78.9	21	0.336	0.1	18.0	9.50	1.52	0.45	81.7	380
or Potatoes 80 per cent. and Onions 20 per cent. . . . .	16	78.8	1.9	0.312	0.16	16.1	8.60	1.4	0.72	73.09	340
or Potatoes 70 per cent. and Canned Tomatoes 30 per cent. . .	16	82.6	1.8	0.300	0.12	14.5	8.17	1.36	0.54	65.8	297
Dried Fruits (average of varieties issued) . . . .	2	29.5	2.9	0.334	1.8	59.7	1.18	0.19	1.02	33.8	147
Sugar . . . . .	2½ gill	25.1	2.4 per cent. nitrogenous matter present, probably not protein	..	..	95.00	..	..	..	64.6	264
or Molasses . . . . .	1½ gill	..	..	..	..	69.3	..	..	..	41.25	198
or Cane syrup . . . .	1½ gill	..	..	..	..	69.5	..	..	..	41.86	198

*Tropical Dietary. I.*

ARTICLES.	Quantity, in ounces.	Fats, gm.	Carbo- hydrates, gm.	Protein, gm.	Nitrogen, gm.	Fuel-value, calories.
Fresh Beef . . .	10	44.75	. . . . .	41.68	6.67	590
Flour . . . . .	18	5.60	380.46	55.08	7.90	1850
Beans . . . . .	2.4	1.22	40.18	15.16	2.42	240
Potatoes . . . .	16.0	0.45	81.70	9.50	1.52	380
Dried Fruit . . .	3.0	1.53	33.80	1.77	0.27	220
Sugar . . . . .	3.5	. . . . .	94.25	. . . . .	. . . . .	397
Total . . . . .	52.9	53.55	630.39	123.19	18.78	3677

Total carbon, 395.14 gm. Nitrogen to carbon, 1 : 19.6.

“This table shows the nutrient value of a proposed dietary for the tropics, containing the greatest amount of food-material, which might be drawn by the soldier.

“The following table shows a proposed dietary for the tropics, especially applicable to field service, in which the fatty constituents attain their maximum and the potential energy is high.

*Tropical Dietary. II.*

ARTICLES.	Quantity in ounces.	Fats, gm.	Carbo- hydrates, gm.	Protein, gm.	Nitrogen, gm.	Fuel-value, calories.
Bacon . . . . .	6	105.06	. . . . .	15.64	2.49	1042
Hard Bread . . .	18.	6.63	371.81	73.12	11.74	1926
Beans . . . . .	2.4	1.22	40.18	15.16	2.42	240
Dried Fruit . . .	3.0	1.53	50.70	1.77	0.27	220
Sugar . . . . .	3.5	. . . . .	94.25	. . . . .	. . . . .	397
Total . . . . .	32.8	114.44	556.94	105.69	16.92	3825

Total carbon, 328.76 gm. Nitrogen to carbon, 1 : 23.

“The nutrient value of the ordinary dietary as proposed for garrison duty in the tropics is as follows :

*Tropical Dietary. III.*

ARTICLES.	Quantity in ounces.	Fats, gm.	Carbo- hydrates, gm.	Protein, gm.	Nitrogen, gm.	Fuel-value, calories.
Fresh Beef . . .	10	44.75	. . . . .	41.68	6.67	590
Soft Bread . . .	20	6.80	299.20	53.83	8.61	1506
Potatoes and On- ions . . . . .	16	0.72	73.09	8.60	1.40	340
Dried Fruit . . .	3	1.53	50.70	1.77	0.27	220
Sugar . . . . .	3.5	. . . . .	94.25	. . . . .	. . . . .	397
Total . . . . .	52.5	53.80	517.24	105.88	16.95	3053

Total carbon, 328.76 gm. Nitrogen to carbon, 1 : 18.

“For the following combination the several articles of the ration most closely approaching in character to the food-materials used by natives of the tropics—proportioned in quantity according to the standard proposed for hot climates—have been selected.

*Tropical Dietary. IV.*

ARTICLES.	Quantity in ounces.	Fats, gm.	Carbo- hydrates, gm.	Protein, gm.	Nitrogen, gm.	Fuel-value, calories.
Fresh Fish (cod) whole . . .	14	0.79	. . . . .	81.73	5.07	120
Soft Bread . . .	20	6.80	299.20	53.83	8.61	1506
Rice . . . . .	4	0.45	88.87	8.75	1.40	407
Potatoes and To- matoes . . .	16	0.54	65.80	8.17	1.36	297
Dried Fruit . . .	3	1.53	50.70	1.77	0.27	220
Sugar . . . . .	3.5	. . . . .	94.25	. . . . .	. . . . .	341
Total . . .	64.5	10.11	598.82	104.25	16.71	2947

Total carbon, 327.50 gm. Nitrogen to carbon, 1 : 19.6.

“On averaging these four dietaries, as furnished by the ration proposed for the tropics, the mean nutrient composition is seen to be as follows :

DIETARY.	Quantity in ounces.	Fats, gm.	Carbo- hydrates, gm.	Protein, gm.	Nitrogen, gm.	Fuel-value, calories.
No. I. . . . .	52.9	53.55	630.39	123.19	18.78	3677
No. II. . . . .	32.9	114.44	556.94	105.69	16.92	3825
No. III. . . . .	52.5	53.80	517.24	105.88	16.95	3053
No. IV. . . . .	64.5	10.11	598.82	104.25	16.71	2947
Average . . .	50.7	57.97	560.85	109.06	17.34	3375

Total carbon, 350 gm. Nitrogen to carbon, 1 : 20.





“It will be observed that while the above dietaries differ considerably among themselves, yet when averaged together in equal proportions they do not greatly vary from the nutritive standard for the tropics already proposed—and this is an additional reason why a selection of the same articles of the ration should not be made from day to day. It is seen that the above average dietary, as compared with the nutrient standard, is still slightly deficient in fats and fuel-value and a trifle in excess as regards protein. These defects, if they may be considered as such, are, however, readily corrected by a rotation of dietaries, in which dietary II. is used twice where dietaries I., III., and IV. are each employed but once. The results of this change are as follows :

DIETARY.	Quantity in ounces.	Fats, gm.	Carbo- hydrates, gm.	Protein, gm.	Nitrogen, gm.	Fuel-value, calories.
No. I. . . . .	52.9	53.55	630.39	123.19	18.78	3677
No. II. . . . .	32.9	114.44	556.94	105.69	16.92	3825
No. II . . . . .	32.9	114.44	556.94	105.69	16.92	3825
No. III. . . . .	52.5	53.80	517.24	105.88	16.95	3053
No. IV. . . . .	64.5	10.11	598.82	104.25	16.71	2947
Average . . . . .	47.1	69.43	572.06	108.38	17.26	3465

Total carbon, 863.33 gm. Nitrogen to carbon, 1 : 21.

“ From the above tables it is evident that such changes as are advisable in the adaptation of the United States Army ration to tropical conditions are chiefly in the line of a reduction in quantity

ARTICLES.	Quantity per ration, ounces.	Protein, gm.	Nitrogen, gm.	Fats, gm.	Carbohydrates, gm.	Fuel-value, calories.
Fresh Beef (quarters) . . . . .	10.0	41.68	6.67	44.75	. . .	590
or Fresh Mutton . . . . .	10.0	46.20	7.35	62.90	. . .	720
or Pork . . . . .	6.0	27.54	4.40	112.54	. . .	1098
or Bacon . . . . .	6.0	15.64	2.49	105.06	. . .	1042
or Salted Beef . . . . .	10.0	40.27	6.44	64.68	. . .	688
or Dried Fish (cod) . . . . .	10.0	45.37	7.26	1.13	. . .	197
or Fresh Fish, average ( whole) . .	14.0	31.73	5.07	0.79	. . .	120
Flour . . . . .	18.00	55.00	7.90	5.60	380.46	1850
or Soft Bread . . . . .	20.00	53.83	8.61	6.80	299.20	1506
or Hard Bread . . . . .	18.00	73.12	11.74	6.63	371.81	1926
or Corn-meal . . . . .	20.00	50.40	7.99	12.40	425.80	1986
Beans . . . . .	2.4	15.16	2.42	1.22	40.18	240
or Peas . . . . .	2.4	16.38	2.62	0.75	41.80	246
or Rice . . . . .	4.0	8.75	1.40	0.45	88.87	407
or Hominy . . . . .	4.0	9.20	1.47	0.67	88.75	430
Potatoes . . . . .	16.0	9.50	1.52	0.45	81.70	380
or Potatoes 80 per cent. and Onions 20 per cent. . . . .	16.0	8.60	1.40	0.72	73.09	340
or Potatoes 70 per cent. and Canned Tomatoes 30 per cent. . .	16.0	8.17	1.36	0.54	65.80	297
Dried Fruit (average) . . . . .	3.0	1.77	0.27	1.53	35.80	220
Sugar . . . . .	3.5	. . .	. . .	. . .	94.25	397
or Molasses . . . . .	1 gill	. . .	. . .	. . .	56.05	269
or Cane-syrup . . . . .	1 gill	. . .	. . .	. . .	56.25	269
Coffee, green . . . . .	$1\frac{3}{5}$					
or Coffee, roasted . . . . .	$1\frac{2}{5}$					
or Tea, green or black . . . . .	$\frac{2}{5}$					
Vinegar . . . . .	$\frac{8}{5}$ gill					
Salt . . . . .	$\frac{1}{6}$ oz.					
Pepper, black . . . . .	$\frac{1}{5}$ oz.					
Soap . . . . .	$\frac{1}{4}$					
Candles . . . . .	$\frac{6}{5}$					

	Standard dietary as given by typical dietaries of men at hard labor in the northern portion of the temperate zone.
	Standard dietary as given by proposed U. S. Army ration for tropical service.
	Standard dietary for native laborers in the tropics; based on the weight of 145 pounds for purposes of comparison.
	Standard dietary of the laboring class of natives in the tropics (Java, British India, Guadeloupe, Abyssinia), as determined from the food actually consumed by them at normal body-weights.

of the foods at present provided by a too generous government. It is true that the sugars and starches should be slightly augmented, but their increase is small when compared with the considerable reduction of nitrogenous and fatty material which is proposed. Many of the components of the present ration, as is seen by the above table, require no change in the consideration of the trop-

ical dietary, being not only admirably selected, but also properly proportioned."

The ideal ration for an army of United States soldiers on duty in the tropics is therefore suggested as being of the composition given in the table on page 137.

Most valuable, instructive, and revolutionary are the experiments conducted by Prof. R. H. Chittenden, of the Sheffield Scientific School, during 1903, and reported by him in a book entitled *Physiological Economy in Nutrition*, published in 1904. These experiments were made on three classes of men—professional men, soldiers, and college athletes. We can but give a résumé of the most important facts established by Prof. Chittenden, referring our readers to the book itself, with the opinion that it is the most valuable contribution on the subject of which it treats which has been made in recent years.

The experiments on the professional men showed that, taking the Voit standard (p. 130) as a general average of accepted diets, this is entirely too generous for a man whose occupation does not involve excessive muscular work, but whose activity is mainly mental; that such a man can live on a much smaller amount of proteid or albuminous food than is usually considered essential for life, without loss of mental or physical strength and vigor, and with maintenance of body and nitrogen equilibrium. Prof. Chittenden himself, whose body-weight was 57 kilos, showed for nearly nine consecutive months an average daily metabolism of 5.7 grams of nitrogen. His wants were met by the metabolism of 33.75 grams of proteid per day, instead of the 118 grams of Voit. At the same time non-nitrogenous food was much reduced below Voit's standard. A fuel-value of 2000 calories per day was adequate to meet the ordinary wants of the body. By experiments upon himself and others Prof. Chittenden has shown that the minimal proteid requirement for professional men is from 0.093 to 0.130 gram of nitrogen per kilo of body-weight. These results were not obtained on a restricted diet, each individual being allowed perfect freedom of choice. The food of a single day is an illustration of this:

**Breakfast—7.45 A. M.**

	Grams.
Coffee . . . . .	103
Cream . . . . .	30
Sugar . . . . .	10

**Lunch—1.30 P. M.**

Creamed Codfish . . . . .	64
Potato balls . . . . .	54
Biscuit . . . . .	44
Butter . . . . .	22
Tea . . . . .	120
Sugar . . . . .	10
Wheat griddle-cakes . . . .	133
Maple syrup . . . . .	108

**Dinner—6.30 P. M.**

	Grams.
Creamed potatoes . . . . .	85
Biscuit . . . . .	53
Butter . . . . .	15
Apples—celery—lettuce salad	50
Apple pie . . . . .	127
Coffee . . . . .	67
Sugar . . . . .	8
Cheese-crackers . . . . .	17



The experiments with the soldiers showed that 50 grams of proteid per day were sufficient for the needs of the body, and that a fuel-value of 2500 to 2600 calories was ample to meet their requirements. At the end of the period of training these men were in excellent condition, although in some there was a slight loss of body-weight.

The result of experiments upon the college athletes was not materially different from that stated in connection with the soldiers. The amount of nitrogen excreted daily averaged 8.8 grams, implying a metabolism of about 55 grams of proteid matter per day.

Prof. Chittenden states in conclusion that he can point to various persons who, for periods varying from six months to a year, have metabolized daily 5.5 to 7.5 grams of nitrogen instead of 16 to 18 grams—*i. e.*, they have subsisted quite satisfactorily on an amount of proteid food daily equal to one-third or one-half the amount ordinarily considered as necessary for the maintenance of health and strength, and this without unduly increasing the amount of non-nitrogenous food; that there is marked increase in physical strength as demonstrated by repeated dynamometer tests on many individuals, which he thinks may be ascribed to the greater freedom of blood and lymph, as well as of muscle-plasm, from nitrogenous extractives. Nor has he been able to find any falling off in mental vigor, or any change in the hemoglobin-content of the blood, or in the number of erythrocytes. He believes that any excess of food over and above what is needed imposes an unnecessary strain upon the organism, and especially upon the excretory organs, and conduces to disease, especially rheumatism and gout.

Age is another important factor which enters into the problem of the dietary. In early life, not only must the waste of the tissues be met, but there must be growth by increase of tissue. In estimating the amount of food to be given to a child as compared with an adult, it is not the weight of the body which is to be taken into account, but its surface, as it is to this that the waste is proportional. Thus a child weighing 20 kilos will present a body-surface about one-half that of a man weighing 70 kilos, and it would require therefore one-half as much food as an adult. As we have already seen, milk is, or should be, the sole diet of the child up to the age of eight months, and in this food we have a diet which contains twice as much proteid and half again as much fat as the adult diet referred to above. Some one has said that "The poorest mother in London or New York feeds her child as if he were a prince. Perhaps not once in a hundred times is the man as richly fed as the young child, unless accident has made him a Gaucho, or study and reflection a gourmand."

Having discussed food-stuffs, we will now turn our attention to some of the more common foods in which these occur.

## MILK.

As already stated, milk is the sole food for the developing child during the early months of its existence, and indeed, as among the Eskimos, for a period extending into years. It is therefore a perfect food, inasmuch as it contains all that is needed for growth and the maintenance of the body in a physiologic condition. This is true for the early period of life, but not for the later, as it contains too little iron and too much proteid and fat, although adults have lived for months on milk alone.

Milk is an emulsion in which the globules of fat are suspended in a fluid, called milk-plasma. As in other emulsions, so here, the white color is due to reflection of light from the globules. It is now believed that the fat is not enclosed in a thin envelope of caseinogen, but that by molecular attraction each globule is covered by a closely adherent layer of milk-plasma. The diameter of the globules varies from 0.0015 to 0.05 mm.

The specific gravity of both cows' and human milk is from 1028 to 1034.

The reaction of milk varies in different classes of animals. In carnivora it is acid, but in most other animals it is either slightly alkaline or neutral.

Milk contains the following ingredients, the quantity varying in the milk of different animals: Water, caseinogen, lactalbumin, lactoglobulin, lactose, fat, extractives, as creatin, creatinin, hypoxanthin, cholesterin, and traces of urea, salts, and the gases oxygen, nitrogen, and carbon anhydrid.

**Human Milk.**—The first milk secreted by the mammary glands is *colostrum* (Fig. 86). It is a yellowish liquid, more alkaline than the milk secreted later in lactation, and contains

very little caseinogen, sometimes none at all, but lactoglobulin and lactalbumin. Colostrum is regarded by some writers as having a distinct cathartic action on the newborn child; others deny that it possesses any such power. The following table contains analyses by Clemm of human milk before and immediately after delivery:

FIG. 86.—Colostrum and ordinary milk-globules, first day after labor; primipara aged nineteen (after Haskell).

CONSTITUENTS.	Four weeks before delivery.		Seventeen days before delivery.	Nine days before delivery.	Twenty-four hours before delivery.	Two days after delivery.
	I.	II.				
Water . . . . .	94.52	85.2	85.17	85.85	84.38	86.79
Solids . . . . .	5.48	14.8	14.83	14.15	15.62	13.21
Casein . . . . .						2.18
Albumin and Globulin . .	2.88	0.9	7.48	8.07		
Fat . . . . .	0.71	4.1	3.02	2.35		4.86
Lactose . . . . .	1.73	3.9	4.37	3.64		6.10
Salts . . . . .	0.44	0.44	0.45	0.54	0.51	

Lactoglobulin, which is found in colostrum, exists in but very minute amount in milk fully formed.

A comparison of the above analyses shows considerable variation; indeed, such variation is found in the milk of the two breasts of the same woman and in women of different ages. Some authorities attribute differences to complexion also.

The salts of human milk are sodium lactate, chlorid, carbonate, phosphate, and sulphate; potassium chlorid and sulphate; calcium carbonate and phosphate; magnesium phosphate; and ferric phosphate.

In the following table by Halliburton are given various analyses of fully formed human milk:

Water.	Casein-ogen.	Albu-min.	Fat.	Sugar.	Salts.	Remarks.	Observers.
88.58	3.69	3.53	4.3	0.17		9 days after delivery.	} Clemm. Tidy.
90.58	2.91	3.34	3.15	0.19			
86.27	2.95	5.37	5.13	0.22			
86.3 } to } 88.8 }	1.68 to 3.15	{ 2.6 to }	{ 5.8 to }	{ 0.23 to }		. . . . .	} Biel.
89.1		5.4	6.6	0.34			
87.24	1.79	3.3	5.4	0.42		Woman 20-30 years old.	} Gerter. Christenn. Pfeiffer. Mendus de Leon.
89.29	1.9	4.3	5.9	0.28			
89.06	1.6	3.2	5.8	0.16			
87.79	1.72	2.9	6.0	0.2			
	2.53	3.9	5.5	0.25		" 30-40 "	

**Cows' Milk.**—The following analysis of cows' milk may be regarded as a sample of many analyses which have been recorded, and will enable a comparison to be made with human milk.

*Analysis of Cows' Milk (Simon).*

Water . . . . .	86.95
Casein } Albumin }	4.40
Fat (butter) . . . . .	3.65
Lactose . . . . .	4.25
Inorganic salts . . . . .	0.75

*Comparative Analyses of Human Milk and Cows' Milk.*

	Human Milk.	Cows' Milk.
Water . . . . .	88.05	86.95
Casein and albumin . . . . .	2.45	4.40
Fat (butter) . . . . .	3.40	3.65
Lactose . . . . .	5.75	4.25
Inorganic salts . . . . .	0.35	0.75

If a comparison is made between the milk of the human being and that of the cow it will be seen that cows' milk contains more proteid, 4.40 as compared with 2.45; more fat, 3.65 to 3.40; and more inorganic salts, 0.75 to 0.35; but, on the other hand, less sugar, 4.25 to 5.75. It results from this that in substituting cows' milk for mother's milk in the feeding of infants the milk should be diluted and sugar added.

In the consideration of the carbohydrates lactose or sugar of milk was discussed, so that here we need only refer to it. As we then learned, this variety does not undergo the alcoholic fermentation with yeast, but does with some other ferments.

The fat of cows' milk is a mixture of palmitin, stearin, and olein, together with triglycerids of butyric, caproic, and other acids. It also contains lecithin, cholesterin, and a yellow lipochrome. The fats of human milk differ somewhat from those of cows' milk, but these differences are not important.

The proteids of milk are, as already stated, caseinogen, which is by far the most important, and lactalbumin and lactoglobulin, which two are present in but minute quantities. Of caseinogen and its properties we have already spoken.

It is this constituent which, when milk coagulates, becomes casein, forming with fat the *coagulum* or *curd*; the liquid portion, which contains whey-proteid, lactalbumin, lactose, and salts, being *whey*. Milk is almost entirely free from purin in any form (p. 434).

Cows' milk is a fluid which is very prone to undergo fermentative changes; one of these, the formation of lactic acid from lactose, has already been described; but there are others, which are perhaps more harmful, being especially irritating to the delicate mucous membrane of the alimentary canal of the young infant. These changes are brought about by various bacteria which find their way into the milk at the dairy, where the milk is produced, or subsequently, either during transportation or after it has been delivered to the customer. Great pains should be taken to keep the surroundings of dairy and home in a cleanly condition.

Milk may be the transmitter of specific disease if taken from a diseased animal—as, for instance, one suffering from tuberculosis; and it may also become infected after coming from the cow and before it is used as food. Numerous epidemics of enteric or typhoid fever have been traced to infection of the milk-supply

by polluted water used either to dilute the milk or to wash the cans which contained it; scarlet fever, also, has been contracted by those who have drunk milk which had become infected by the hands of milkers who were recovering from the disease. Diphtheria has also been transmitted through infected milk.

In order to prevent the fermentation of milk, the bacteria contained in it should be destroyed. This may be done either by sterilization or pasteurization.

Sterilization consists in heating the milk to 100° C., the boiling-point, by which the milk becomes "sterile"—that is, all organisms which would produce fermentative changes in the milk are killed. The objections to this process are that the taste of the milk is altered to that of boiled milk, the casein is not so easily digested, the emulsification of the fat and its absorption are not so readily brought about, and the amylolytic enzyme is destroyed. If the exposure to the heat continues too long, the milk becomes brownish in color, due to the conversion of lactose into caramel.

In pasteurization the milk is exposed to a temperature of only 71° C. to 76° C. for fifteen to twenty minutes; milk thus treated is not changed as in sterilization, but will keep only a short time—a day or two.

Human milk is the product of the mammary glands, the structure of which may here be concisely described.

#### MAMMARY GLANDS.

The mammary glands or mammæ (Fig. 87) are two in number, situated one in each pectoral region. They are compound racemose glands, and consist of gland-tissue which is made up of lobes, and these again of lobules (Fig. 88). The lobes are connected by fibrous tissue, and between them is fat. Each lobule is composed of sacculated alveoli and a duct, the lobular duct. The lobular ducts discharge into larger ducts, which in turn discharge into a lactiferous duct, which may be regarded as the excretory duct of a lobe. Of these ducts, *tubuli lactiferi*, there are from fifteen to twenty. They open at the surface of the prominent point of the breast, the *mammilla* or nipple, surrounding which is the *areola*, which in the virgin is of a pinkish color, becoming darker during pregnancy and almost black at its termination. Under the areola the *tubuli lactiferi* are dilated, forming *ampullæ*, in which, during the period of lactation, the milk accumulates in the intervals of nursing. When these reservoirs are full the tension of the gland stops the process until they are emptied by the sucking child, when the cells again take on their function and the milk is secreted and flows into the *ampullæ* through the ducts, there to accumulate until the next nursing.

The walls of the alveoli consist of a basement-membrane, covered, during the period when the gland is not active, by a single layer of flat or cuboidal cells (Fig. 90) with one nucleus and presenting a granular appearance. There are at this time no fat-globules. When, however, the gland begins to take on an active condition (Fig. 91) these cells become higher and project into the interior of the alveoli, and the single nucleus divides, thus becoming two. In the cytoplasm drops of fat appear, especially at the ends of the cells nearest the interior of the alveoli, and at the same time the nucleus which is nearer to this end of the cell becomes fatty. This end of the cell then breaks down, and the

FIG. 87.—Arrangement of glandular tissue of breast, the fat having been removed to show the ducts and acini (Astley Cooper).

material forms the albuminous ingredients of the milk and the lactose, while the drops of fat become the milk-globules. The portion of the cell which remains forms new cytoplasm, and the same process is repeated over and over again. The cells also secrete water and the salts which are found in the milk.

There is some difference of opinion as to the origin of the corpuscles found in the colostrum, and which are known as colostrum-corpuscles. One view is that they are epithelial cells of the alveoli, which become rounded and in which fat is developed, and that in this condition they become detached and are discharged into the cavity of the alveolus. Another view is that

they are emigrated lymph-corpuscles; while still a third regards them as derived from the wandering cells of the connective tissue.

When the period of lactation is over the glands return approximately to their original condition, thus undergoing the process of *involution*.

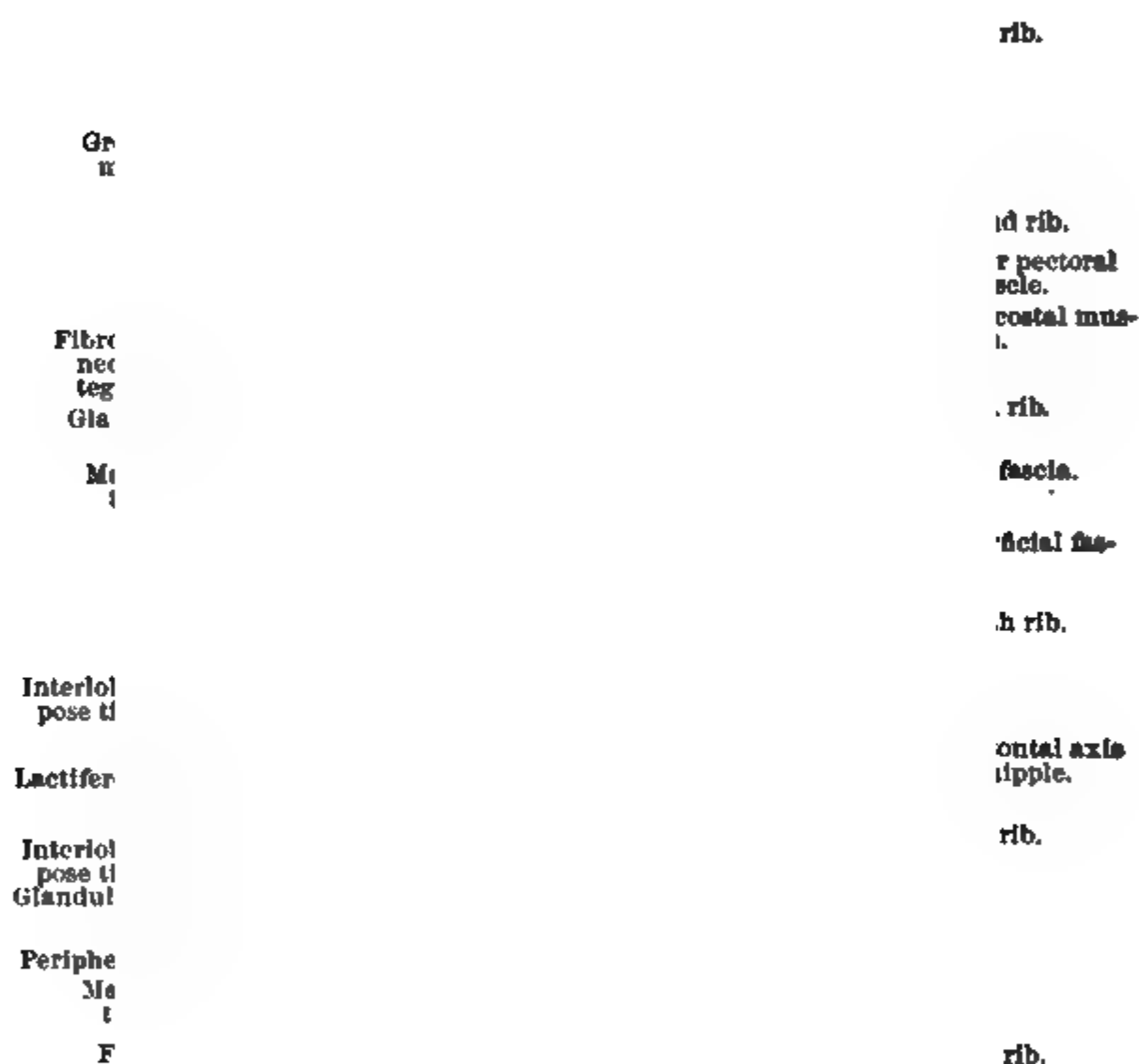


FIG. 88.—Longitudinal section of mammary gland *in situ*; frozen subject of twenty years (Testut).

That the secretion of milk is under the control of the nervous system there is no doubt, for the instances are numerous in which strong emotions of grief or anger have caused the secretion to cease, but just what the relation is remains still undecided. It may be that secretory nerves are involved in the activity of these glands, or that it is through the influence of vasomotor fibers that

their secretion is produced ; but experiments have as yet not determined the question. That the glands may act automatically is

FIG. 89.—From section of mammary gland of nullipara (from Nagel's "Die weiblichen Geschlechtsorgane," in *Handbuch der Anatomie des Menschen*, 1886).

proved by the fact that when all the nerves which supply them are divided, the secretion still continues to be formed.

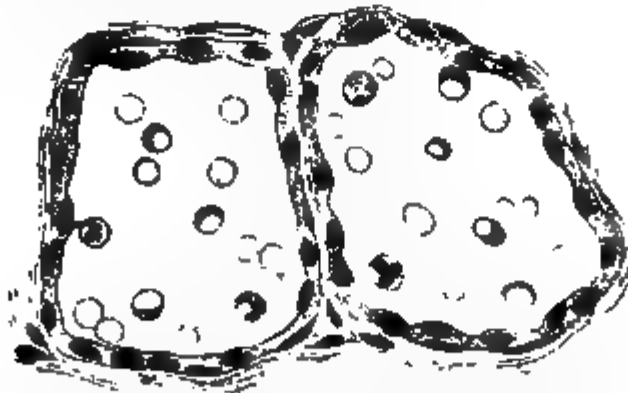


FIG. 90.—Section through the middle of two alveoli of the mammary gland of the dog ; condition of rest (after Heidenhain).

The table on page 149 gives the composition of milk and other food-materials, together with their nutritive value. It is from one of the *Farmers' Bulletins*, "Milk as Food," issued by the United



States Department of Agriculture. Incidentally we would call attention to these publications, which are issued free or at a



FIG. 91.—Mammary gland of dog, showing the formation of the secretion: *A*, medium condition of growth of the epithelial cells; *B*, a later condition (after Heidenhain).

nominal cost by the Government, and are full of practical value, not alone to farmers, but to all students of economics.

### EGGS.

Eggs in various forms enter largely into the common dietary. So far as birds are concerned, eggs may be regarded as a perfect food, inasmuch as until the young leaves the shell all its nutrition has been obtained from the shell and its contents, together with what it has obtained from the atmosphere.

The egg of the hen is the one commonly used as food, although ducks' eggs are eaten to a considerable extent. In a hen's egg weighing 50 grams there are 7 grams of shell, 27 grams of the white, and 16 grams of yolk. The yolk and white are made up of water, 73.5; proteids, 13.5; fats, 11.6; and salts, 1 per cent.

The white of egg consists of egg-albumin, egg-globulin, and ovomucoid, with some sugar, fat, lecithin, cholesterin, and salts.

The yolk is composed of two kinds of material, one yellow, containing fat and the yellow coloring-matter lipochrome, and the other nearly white in color in which is found the nucleoproteid, vitellin, together with sugar, lecithin, cholesterin, and salts, as in the white.

The white of the egg in its raw state is more digestible than when cooked, but there are few persons to whom raw eggs are palatable. Egg-albumin is coagulated at a temperature of 73° C., and vitellin at 75° C. When the temperature reaches 100° C., the boiling-point, and is kept there for some time, the albumin is so thoroughly and densely coagulated as to be difficult of digestion.

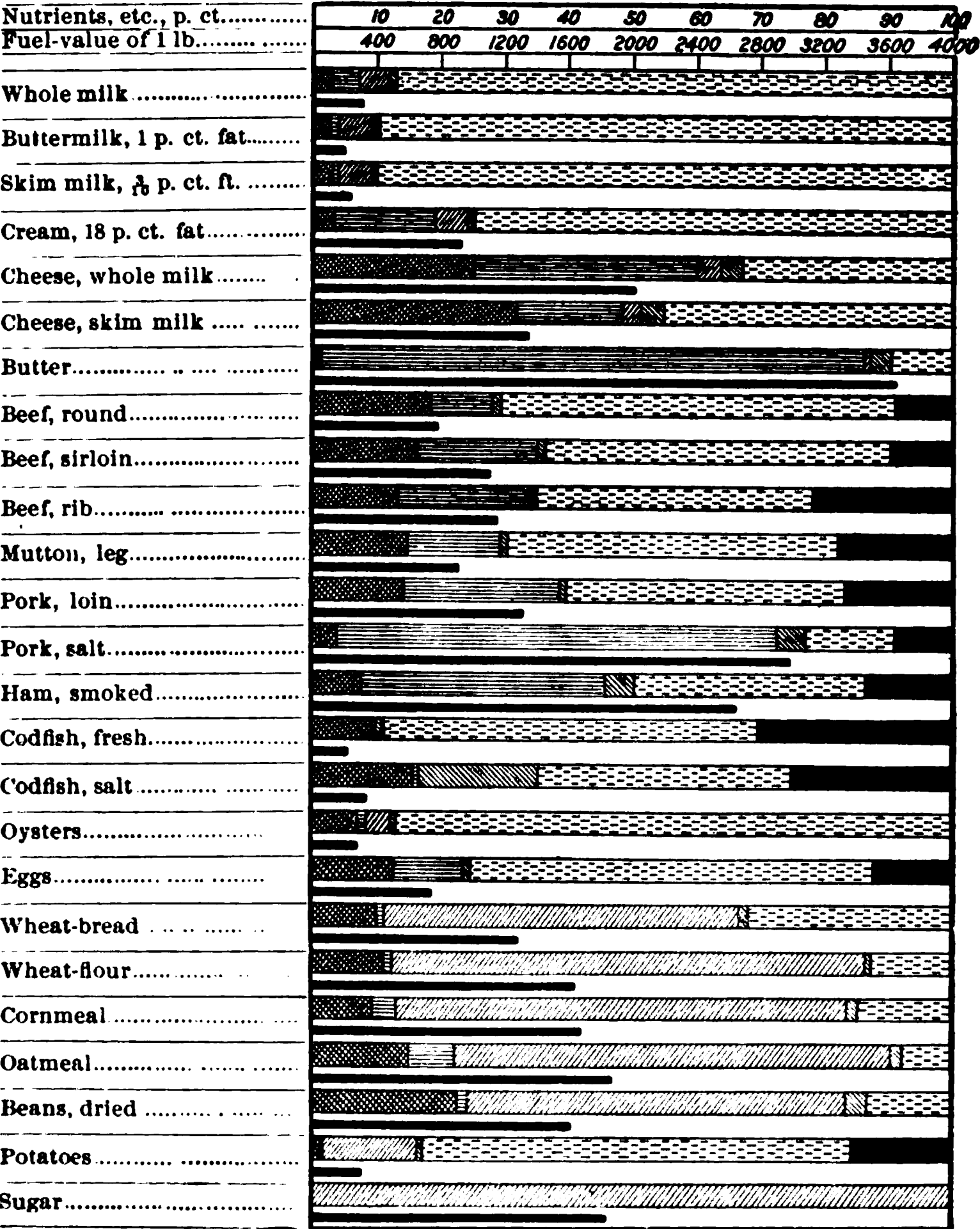
Eggs have a high nutritive value, being so rich in proteid constituents, but must be supplemented by carbohydrates, in which they are very deficient. They contain no free purin or purin-yielding bodies (p. 434), and are therefore useful when a diet free

COMPOSITION OF MILK AND OTHER FOOD-MATERIALS.

Nutritive ingredients, refuse, and fuel-value.



*Protein* compounds, *e. g.*, lean of meat, white of egg, casein (curd) of milk, and gluten of wheat, make muscle, blood, bone, etc.  
*Fats*, *e. g.*, fat of meat, butter, and oil, } serve as fuel to yield heat and muscular  
*Carbohydrates*, *e. g.*, starch and sugar, } power.



from purin is desired. Eggs with milk in which the amount of purin is very small, together with butter and cheese, makes a diet almost entirely free from purin free or bound.

### MEAT.

Meat is the flesh of such vertebrate animals as are used for food, though the term is perhaps commonly restricted to the muscular tissue of mammals. It is the kind of food from which the nitrogen necessary for nutrition is chiefly obtained. In meat there are not only connective and adipose tissue, in addition to muscular fiber, but even in the leanest meat there are fat-cells between the muscular fibers.

In the following table (Munk) are given the percentages in which the various constituents occur in the meats of the common mammals used as food, together with those of fowl and pike.

Constituents.	Ox.	Calf.	Pig.	Horse.	Fowl.	Pike.
Water . . . . .	76.7	75.6	72.6	74.3	70.8	79.3
Solids . . . . .	23.3	24.4	27.4	25.7	29.2	20.7
Proteids and Gelatin	20.0	19.4	19.9	21.6	22.7	18.3
Fat . . . . .	1.5	2.9	6.2	2.5	4.1	0.7
Carbohydrates . .	0.6	0.8	0.6	0.6	1.3	0.9
Salts . . . . .	1.2	1.3	1.1	1.0	1.1	0.8

We have already discussed the chemical composition of muscle (p. 62), and therefore need simply refer to it here.

Liebig states that the flesh of young animals contains more gelatin than that of old ones; in 1000 parts of beef there are 6 parts of gelatin, while in veal there are 50 parts. It is a matter of common belief that veal is less digestible than beef. This is, perhaps, true to some extent, but not to such an extent as is generally thought. Veal is more tender than some other meats, and is therefore not usually well masticated, and hence not sufficiently prepared for the action of the digestive juices. This renders its digestion difficult and leads to the inference that its digestibility is low. When very young, veal has a gelatinous consistency and is regarded as being unfit for food.

The cooking of meat has the effect of making it more digestible by changing its collagen into gelatin, and also more palatable. Besides this, if the temperature is carried sufficiently high, any animal parasites or pathogenic bacteria which the meat may contain are killed. Whenever meat is eaten which is raw or insufficiently cooked, there is always danger of contracting disease. Meat which contains the *Trichina spiralis* may in this condition produce *trichinosis*; and that which contains *cysticerci* may cause tapeworm in those who eat it. There is also great danger from eating the meat of a tuberculous animal. This is denied by some, but the evidence in its favor seems conclusive to the author.

Until the year 1901 it was the general consensus of opinion among those who had made a study of the subject that bovine and human tuberculosis were identical. In 1895, the Royal Commission on Tuberculosis said: "We find the present to be a convenient occasion for stating explicitly that we regard the disease as being the same disease in man and the food animals, no matter though there are differences in the one and the other in their manifestations of the disease; and that we consider the bacilli of tubercle to form an integral part of disease in each, and (whatever be its origin) to be transmissible from man to animals, and from animals to animals."

In 1901, Koch announced that he felt "justified in maintaining that human tuberculosis differs from bovine, and cannot be transmitted to cattle." He also expressed the opinion that bovine tuberculosis was scarcely, if at all, transmissible to man. Since this announcement of Koch was made, the matter has been investigated all over the world by experienced and competent men, and the practical result of such inquiry is to leave the subject where it was prior to Koch's announcement.

The infection may not be directly due to the ingestion of the meat itself—that is to say, the muscular tissue may not contain the bacilli—but to the tuberculous matter from glands with which in the cutting of the meat the butcher smears it. The *Bacillus tuberculosis* is killed in a few minutes at a temperature of 100° C., the boiling-point, in five minutes at 80° C., and in four hours at 55° C., but the bacillus itself must be exposed to these temperatures. Experiment has demonstrated that in ordinary cooking both by boiling and roasting, the temperature in the interior of the joint of meat, unless it is under six pounds in weight, seldom reaches 60° C.; and that rolled meat, in the center of which is tuberculous matter, is not sterilized by any process of cooking if it is over four pounds in weight. It follows from this that the greatest care and supervision should be exercised by health authorities at the slaughter-house, so as to prevent the possibility of infected meat finding its way into the market. To minimize still further the danger, all meat which may contain infection should be thoroughly cooked.

The cysticerci which develop tapeworm in man are not destroyed by the simple processes of salting and smoking, so that for their destruction meat should be exposed to a temperature of at least 66° C., while for the destruction of the trichina the temperature should be even higher, say 70° C., inasmuch as the trichina is enclosed in a capsule which serves as an obstacle to the entrance of heat.

The common methods of cooking meat are, roasting, boiling, broiling, and frying. These all have their proper places, but should be employed with discrimination. In roasting, the meat is exposed to a great heat, so as to coagulate the proteids on the

surface in as short a time as possible, thus retaining the juices of the meat in the interior. The temperature is then reduced to  $93^{\circ}\text{C}$ . or  $88^{\circ}\text{C}$ ., and maintained at that point, the general rule being to allow fifteen minutes for every pound of meat, otherwise the coagulating process will extend to the interior and make the muscular fibers tough. This temperature is high enough to cook thoroughly the whole piece, but not so high as to dry up the juices. Broiling is allied to the process of roasting. In boiling meat the same object is accomplished by plunging it into boiling water, which coagulates the exterior as in the roasting process.

If, however, the object to be attained is to make soup or broth, then the meat, having been cut into small pieces, is placed for some time in cold water and the temperature gradually raised to  $71^{\circ}\text{C}$ . By this treatment the juices of the meat are extracted and the soluble parts are dissolved out from the meat, before the heat has time to coagulate the proteid. It should be remembered, however, that such soups are not very nutritious, but are stimulating. They contain very little proteid or fat, but do contain salts and the extractives of muscles, such as creatin, creatinin, etc. It is for the reasons thus given that beef-tea is of little value as food. Prof. Halliburton, in a recent address before the American Chemical Society, called attention to the valueless character of beef tea in the following language :

“Beef tea, or ‘beef extract,’ as it is generally termed in the United States, is in no sense a food, but merely a palatable and stimulating drink, ordinarily harmless, though possibly harmful in gouty conditions.

“I have looked in vain among your advertisements for one which is familiar to us in England, representing an ox in a teacup. Another advertisement on a similar line shows an ox looking at a bottle of meat extract and saying, ‘Alas ! my poor brother,’ the inference being that all that is of nutritive value in the ox was contained in the little bottle he is contemplating. The absurdity of these advertisements must be apparent to all who have any knowledge of the chemistry of foods, and it is the province of the physiologist and the chemist to teach the public and the medical profession how erroneous such views are. Instead of an ox in a teacup, the ox’s urine in a teacup would be much nearer the fact, for the meat extract consists largely of products on the way to urea, which much more nearly resemble in constitution the urine than they do the flesh of the ox. The manner in which meat extracts have been pushed in the market will, I fear, stand for a long time in the way of the recognition of the simple truth, that the best way of getting all the available benefit from a mutton chop is just to eat it.

“Some of the manufacturers of meat extracts have lately awakened to the fact that the general public is learning something

of the real value, or lack of value, of their wares, and, with a view to meeting the criticisms which have been raised, they have added greater or less quantities of powdered meat fibers. Even if it is granted that the powdered fibers are digestible, and that the meat extracts are composed wholly of them, which they are not, how much nutriment would the patient receive from teaspoonful doses given through the twenty-four hours? Certainly not an appreciable amount."

If vegetables are added to meat extracts, making a vegetable soup, the nutritive value is correspondingly increased. If bones are used in the soup-making process, the amount of gelatin may be increased to such an extent that when cold the soup gelatinizes and becomes solid.

Frying is a method of cooking which should never be applied to meat such as beef, as it makes it indigestible by reason of its toughness, and also by reason of the fat with which it becomes soaked. If meats are fried by immersion in boiling fat, the process is not so objectionable; but the fat should not be allowed to permeate the tissue, as it would do if the process was continued too long. Frying is well adapted to the cooking of fish.

CEREALS.

The cereals are the farinaceous seeds used as food, such as wheat, Indian corn or maize, rice, rye, oats, and barley. They all contain proteids, fat, starch, and mineral salts, though the proportion of these ingredients varies considerably in the different cereals, as is shown by the following table (Halliburton):

Constituents.	Wheat.	Barley.	Oats.	Rice.
Water . . . . .	13.6	13.8	13.4	13.1
Proteid . . . . .	12.4	11.1	10.4	7.9
Fat . . . . .	1.4	2.2	5.2	0.9
Starch . . . . .	67.9	64.9	57.8	76.5
Cellulose . . . . .	2.5	5.3	11.2	0.6
Mineral Salts . . . .	1.8	2.7	3.0	1.0

The proteids in the flour of cereals are not identical. Some writers regard those in wheat-flour as being a vegetable myosin and a soluble proteose called phytalbumose. Gluten, which is considered by some authorities as a proteid constituent of wheat, is regarded by others as a mixture of gluten-fibrin, which is formed from the vegetable myosin, and a proteose insoluble in water, which is formed from the phytalbumose, and which gives to the gluten its sticky consistency. According to this theory, the gluten as such does not exist until water is added, when by the action of an enzyme gluten is produced. This enzyme has, however, never been isolated, and until this theory is better sustained by proofs we shall regard gluten as a constituent of wheat-flour.



The proteids of oats are three in number: One soluble in alcohol, one a globulin, and the third a proteid soluble in alkali.

In maize there are two globulins, one a vitellin and the other a myosin; one or more albumins; and zein, a proteid soluble in alcohol.

The proteids of rye are gliadin, leucosin, edestin, and proteose; and those of barley are leukosin, proteose, edestin, and hordein.

The cereal most commonly used is, perhaps, wheat, the flour of which is made into bread.

**Bread.**—The cereal most used for bread-making is wheat, though bread is also made from rye and cornmeal. Wheat-flour contains approximately 14 per cent. of water, 12 of proteids, and 70 of carbohydrates. The amount of fat and salts is small. In the making of flour the wheat-grains are ground, and the result is sifted, or “bolted” as it is termed, into fine flour, coarse flour, and bran. The bran is the extreme outer covering of the grain, and is so tough and silicious that it is of no nutritive value, while the other coverings contain so much of proteid, fat, and salts as to give them considerable food-value. The process of making flour just described is known as the *old process*, and results in heating the flour, which, if not properly cooled, is liable to spoil. In the *new process* the grains are cut with knives or crushed between iron rollers which do not produce heat. Flour is made by another process, in which the grains are moistened and the extreme outer covering or husks removed by rubbing. The grains after being dried are exposed to blasts of air which have force enough to thoroughly disintegrate them. When pulverized this is known as *whole-wheat flour*, and contains all that is nutritive in the wheat. In making bread the flour is moistened with water or milk to which yeast has been added, and when thoroughly mixed this becomes dough. Salt is also added, and some breadmakers add sugar and butter as well. After thorough kneading, the dough is exposed to a temperature of about 24° C. The starch is converted by an enzyme which exists in the wheat into dextrin and sugar, and this, under the influence of the yeast, then undergoes the alcoholic fermentation, alcohol and carbonic-acid gas resulting. This gas rises up through the dough, expanding it to more than double its original volume, making it thereby very spongy. When the dough has risen sufficiently, it is put into an oven and baked. This results in killing the yeast-cells, and thus prevents any further fermentation, and at the same time the carbonic acid and alcohol are expelled and the crust is formed. Wheat bread contains 7 to 10 per cent. of proteids, 55 of carbohydrates, 1 of fat, 2 of salts, and 32 to 35 of water.

## VEGETABLES.

The green vegetables form a very important part of the food of man. It is true that they contain a large amount of water, varying from 75 to 95 per cent.; still, they also contain carbohydrates, and are one of the principal sources from which these food-stuffs are derived. Thus in potatoes, while there is but 2 per cent. of proteids, and only 0.2 per cent. of fat, there is 20 per cent. of starch. The pulses or leguminous plants, such as peas, beans, and lentils, supply man in their seeds with food which is rich in proteids as well as in carbohydrates; thus in peas there are 23.7 per cent. of proteid and 49.3 per cent. of starch; in lentils, 24.8 per cent. of proteid and 54.8 per cent. of starch. The proteids of the pulses are of the nature of vitellin and globulin. In the kidney-bean two globulins, phaseolin and phaselin, besides proteose have been found.

**Vegetable Proteids.**—The proteids in vegetables may exist in three forms: (1) In solution in the juices of the plant; (2) in the protoplasm; or (3) in aleurone grains. They are classified, as are the animal proteids, into albumins, globulins, albuminates, proteoses and peptones, and coagulated proteids. What was formerly spoken of as legumin or vegetable casein, or simply vegetable proteid, is now held to be an alkali-albumin produced by the action of the alkali used in the extraction on the globulins which exist normally in the plant. Proteoses have been found in the various varieties of flour, as well as in the circulating fluids of plants, and in the latter also occur hemi-albumose, leucin, tyrosin, and asparagin. Enzymes also exist in plants, and to those of a proteolytic character these proteoses are probably due. Some of these proteolytic enzymes have been carefully investigated, notably papain in the papaw plant, and bromelin in pineapple-juice. In the juice of the papaw are a number of proteids: a globulin resembling serum-globulin, an albumin, and two proteoses, with one of which papain is associated. This enzyme is very much like trypsin.

Bromelin acts in neutral, acid, or alkaline media, acting particularly well at 60° C. It produces proteoses and peptones, and is used to prepare artificially digested foods.

Enzymes are very abundant in the vegetable kingdom, and have for their office the conversion of the insoluble proteid of the seed into the soluble nitrogenous substances of the sap. They are, however, not all of a proteolytic nature. There are also those that are amylolytic, as the diastase in barley, and these enzymes change the starch of seeds into sugar. Such a conversion we have already referred to in the process of bread-making when the wheat-starch first becomes sugar, and then undergoes alcoholic fermentation under the influence of yeast.



The nutritious value of fruits is not to be overlooked. When fresh and ripe they are easily digested, and serve besides a useful purpose in keeping the bowels in regular action.

### BEVERAGES.

Under this general head are included tea, coffee, cocoa, and alcoholic beverages. Some of these have a distinct food-value, others are stimulants only, while the opinions held by authorities as to some of the others are so diverse and the results of experiments so differently interpreted, that it is difficult with our present knowledge to classify them with precision.

**Tea.**—Tea is an infusion made from the leaves or leaf-buds of the tea plant, the principal constituents of which are an aromatic oil, an alkaloid, thein ( $C_8H_{10}N_4O_2$ ) 1.8 per cent., tannin about 15 per cent., albuminous compounds, dextrin, and salts containing potash and phosphoric acid. Tea is a stimulant by virtue of the thein which it contains, and an astringent because of the presence of tannin.

Tea should be made with boiling water, and in about five minutes the infusion should be poured into another vessel; if left longer, it becomes bitter and unwholesome because of the large amount of tannin dissolved.

**Coffee.**—This beverage is an infusion made from the seeds of the coffee plant. The seeds or berries contain fat, legumin or vegetable casein, sugar, dextrin, salts, an aromatic oil, and an alkaloid caffein ( $C_8H_{10}N_4O_2$ ) about 0.75 per cent., and caffeo-tannic or caffeic acid, a variety of tannic acid. Thein and caffein are isomeric, and their effects are similar. While tea is astringent, coffee has a laxative action on the bowels and acts as a stomachic tonic.

It has also been claimed that both tea and coffee act indirectly as foods by retarding the waste of the tissues; whether this is true or not, they certainly have their uses in removing the sense of fatigue, and they also allay the sensation of hunger. If used to excess, however, both coffee and tea disturb the digestive organs and produce nervous disturbances, such as headache, trembling, and wakefulness. This condition is most commonly observed in the confirmed tea-drinker, who is as intemperate as anyone addicted to the excessive use of alcohol. Black coffee increases the heart action, and is given by physicians when the circulation is depressed. It is also given in cases of poisoning by opium. For its relation to uric acid see page 434.

**Cocoa.**—This is prepared from the seeds of *Theobroma cacao*, which are roasted, husked, and crushed. Cocoa-nibs, as the crushed seeds are called, contain about 50 per cent. of oil or cocoa-butter, 15 per cent. of proteids, and an alkaloid, theobromin, 0.5

to 1.2 per cent. This alkaloid is very similar in all respects to thein and caffein.

Cocoa is supposed to possess much more nutritive value than either tea or coffee, and that it is, therefore, especially useful in wasting diseases, during which it is frequently prescribed, but the small amount of proteid and fat contained in a single teaspoonful of cocoa can hardly entitle it to a very high place among foods.

**Alcoholic Beverages.**—Under this head are included spirits, or those that are distilled; wines, those that are fermented; and beers or malt liquors.

Spirits or distilled liquors include whiskey, brandy, rum, and gin.

Whiskey is produced by distilling fermented grain, such as corn or rye. It contains by volume 28.90 to 60.30 per cent., and by weight 23.75 to 52.58 per cent., of alcohol. Brandy is the product of the distillation of fermented grapes, and has an alcoholic strength of 30.80 to 50.40 per cent. by volume and 25.39 to 42.96 per cent. by weight. Brandy contains enanthic and other ethers which whiskey does not. These percentages are the results of actual analyses made by the Board of Health of the State of New York, and differ very markedly from those given by most authorities. Thus we have before us one excellent authority, who states that whiskey contains 44 to 50 per cent. by weight, or 50 to 58 per cent. by volume, of alcohol; and brandy 39 to 47 per cent. by weight, or 45 to 55 per cent. by volume; while another makes the statement that brandy contains from 50 to 60 per cent. of alcohol. It is evident from these figures that the alcoholic strength of different whiskeys and brandies varies to a considerable degree—so much so, indeed, that in using alcohol medicinally physicians are recommended to prescribe “alcohol of a known strength, flavored with ethereal essences, and softened with glycerin or syrup” (Bartley).

Wines differ also greatly in alcoholic strength, the “lighter” wines containing less, the “stronger” wines more. Of the lighter wines, champagne contains from 5.8 to 13 per cent., and red Bordeaux 6.85 to 13 per cent.; while of the stronger wines, port contains from 16.62 to 23.2 per cent., and sherry from 16 to 25 per cent. Wines contain besides alcohol various aromatic compound ethers—enanthic, citric, malic, racemic, etc.—which give to them their “bouquet,” also sugar, tannic acid, various other acids, and potassium salts.

Beers contain on an average from 3 to 6 per cent. of alcohol by volume; although there is here, as in the distilled beverages, a great variation. They also contain dextrin, sugar, lupulin, free organic acids and salts. Purin-bodies (p. 434) have been found in beer and porter. Hall obtained on analysis 0.1250 grams per liter from lager beer and 0.1550 from porter. He remarks that

their presence may account for the harmful influence of these beverages in gout, and for some of the pathologic changes which occur in chronic alcoholism. In claret, sherry, and port no trace of purin-bodies is found. The following table gives the percentages of alcohol and solid matter or extract in some of the common beers and ales (Allen):

	Alcohol.	Solid matter or extract.
Munich Lager . . . . .	4.75	7.08
Pilsen Lager . . . . .	3.55	5.15
American Lager (average of 19 samples) . . . . .	2.78	6.05
Bass's Pale Ale . . . . .	6.25	6.98
Alsop's Pale Ale . . . . .	6.37	4.44
Guinness's Stout . . . . .	6.66	7.24

**Value of Alcoholic Beverages as Food.**—It will be seen that by virtue of the carbohydrates and salts which wines and beers contain they certainly have a food-value entirely irrespective of the alcohol, which is also one of their constituents. The compound ethers are regarded as assisting digestion by promoting the secretion of the digestive fluids, while the bitter principles are well-recognized stomachic tonics. Used in moderation they are therefore not injurious, but used to excess there is danger of their producing fat in excess, imperfect oxidation, and a resulting plethoric and perhaps gouty diathesis.

**EFFECTS OF ALCOHOL UPON THE HUMAN BODY.**

We come now to consider a subject about which volumes have been written, and one which has, perhaps, excited more discussion in both scientific and lay organizations than any other—*i. e.*, the effects of alcohol upon the human body. The warfare has raged long and fierce around the question, “Is alcohol a food?” In a discussion of any subject it is very important that there should be no misunderstanding about the meaning of the terms employed, and, therefore, before entering upon this discussion we must have a distinct understanding as to what is meant by a food. For this purpose we quote the following definitions:

**Definitions of Food.**—“That which is eaten or drunk for nourishment; aliment; nutriment in the scientific sense; any substance that, being taken into the body of animal or plant, serves, through organic action, to build up normal structure or supply the waste of tissue; nutriment, as distinguished from condiment.”—*Standard Dictionary*.

“Anything which, when taken into the body, serves to nourish or build up the tissues or to supply heat.”—*Dorland's Illustrated Medical Dictionary*.

“Any substance, inorganic or organic, solid or liquid, that will

nourish the body, renew the materials consumed in producing those forms of energy called vital.”—Chapman’s *Human Physiology*.

“The use of food is to repair the waste of the tissues, and through combustion in the economy to liberate energy.”—*Ibid*.

These quotations might be increased indefinitely, but those given will answer our purpose. A food serves one or more of four purposes: 1. To build up normal structure; 2. To diminish the waste of tissue; 3. To supply the waste of tissue; 4. Through combustion (oxidation) to liberate energy. Any substance, therefore, which performs any one or more of these four offices is a food. It may do it to a considerable extent, and consequently have great food-value; or it may do it to but a slight extent, and have but little food-value; but in so far as it does it at all it is a food.

**Influence of Alcohol upon Secretion of Saliva.**—When strong alcohol or an alcoholic beverage is taken into the mouth there is produced an increase in the secretion of saliva, not only as to volume, but also as to its organic and inorganic constituents. The same effect is produced by vinegar, ether-vapor, and other similar substances. This stimulating effect, however, lasts only while the liquid is in the mouth. Alcohol in the stomach has no effect upon the secretion of saliva.

**Influence of Alcohol upon Secretion of Gastric Juice.**—The evidence is overwhelming that alcohol, whether taken as alcohol or in the form of alcoholic beverages, such as whiskey, wine, or beer, increases the amount of gastric juice secreted, and that this is more acid and contains more of its normal constituents. The action of this gastric juice upon proteids is also very pronounced. That this is not entirely due to direct stimulation of the glands of the stomach by the alcohol is shown by the fact that when alcohol is introduced into the small intestine, and then this latter is ligated so that none of the alcohol can enter the stomach, an increased secretion of gastric juice is still produced. It is as yet not determined just how this is brought about, whether by action on the cells of the gastric glands through the medium of the blood, or upon secretory nerve-fibers.

It is to be borne in mind that other constituents than alcohol are to be found in wines and malted liquors; and experiments show that these, especially the organic acids, produce also a stimulating effect upon the gastric glands, so that the alcohol is not the only factor concerned in causing increased secretion and acidity.

**Influence of Alcohol upon Gastric Digestion.**—In a paper on “Influence of Alcoholic Drinks upon Digestion,” by Chittenden, Mendel, and Jackson, published in the *American Journal of Physiology*, and to which we are indebted for much information, is a synopsis of the opinions and results of experiments

of different physiologists on this part of the subject. Kretschy observed in a woman with gastric fistula that alcohol retarded digestion. Buchner found that in the human stomach alcohol, wine, and beer retarded digestion, but less so than in artificial digestion. Bikfavi observed in dogs a retardation of digestion with even small quantities of alcohol. Beer and wine showed no favorable influence, the latter retarding digestion in large quantities. Ogata states that beer, wine, and brandy retard digestion noticeably. Schelhaas observed that in the living stomach wine did not retard digestion so long as there was free HCl present. Gluzinski found that alcohol retarded proteid digestion and brought about the secretion of a very active, strongly acid gastric juice. Henczincki observed no bad effect on digestion with the use of beer. Blumenau found that 25–50 per cent. alcohol diminishes stomach digestion during the first two or three hours. Wolffhardt observed in a healthy man that 15–20 grams of absolute alcohol interfered with proteid digestion; that the effect of cognac varied with the period of digestion during which it was taken; and that wines tended to promote digestion. Brunton states that alcohol increases the movements and the secretion of the stomach, and by mixing its contents more thoroughly with gastric juice accelerates digestion. Gluzinski on the other hand, finds that alcohol diminishes the mechanical action of the stomach to a moderate degree.

Chittenden and his associates experimented upon a dog to ascertain the effect of alcohol upon (1) variations in acidity and (2) time of digestion. The results are very interesting and instructive.

In these experiments 50 grams of meat were given in each, sometimes alone, sometimes with water, and sometimes with alcohol of varying strengths, and sometimes with various alcoholic beverages. When meat alone was given the stomach was empty (end of gastric digestion) in 2 hours and 55 minutes. When water was given with the meat, the time of digestion varied from 2 hours and 15 minutes to 3 hours; an average of 2 hours and 40 minutes. With alcohol, varying from 22 to 30 per cent., the time was from 3 hours to 3 hours and 45 minutes; average, 3 hours and 20 minutes. With weak alcoholic beverages, wine and beer, the time of digestion was from 3 hours to 3 hours and 15 minutes; average, 3 hours and 10 minutes. With strong alcoholic beverages, it was with whiskey, 2 hours in one experiment and 3 hours in another; with gin, 3 hours; with brandy, 2 hours and 40 minutes; an average of 2 hours and 40 minutes. The conclusions to be drawn from these experiments would seem to be that alcohol does not retard proteid digestion to any great degree; taking the set of experiments quoted in connection with another set, there is a slight retardation, and that more marked with malted beverages.

Inasmuch, however, as we have already seen, an increased amount of an active gastric juice is produced by the alcohol, it is more than probable that this makes up for any retardation in the proteolytic processes.

The great care with which these experiments of Chittenden and his associates have been made seems to the writer to entitle their conclusions to great consideration, which may be briefly summed up in the statement that "gastric digestion in the broadest sense is not markedly varied under the influence of alcohol or alcoholic fluids. This conclusion, it may be mentioned, stands in perfect harmony with the results of the investigations of Zuntz and Magnus-Lenz regarding the influence of alcohol (beer) on the digestibility and utilization of food in the body. These investigators found by a series of metabolic experiments on men with diets largely made up of milk and bread, and on individuals accustomed and unaccustomed to the use of alcoholic beverages, that the latter did not in any way diminish the utilization of the food by the body."

**Influence of Alcohol and Alcoholic Fluids upon the Excretion of Uric Acid.**—Beebe has conducted a series of experiments reported by Chittenden in the *American Journal of Physiology*, with : 1, Absolute alcohol suitably diluted ; 2, whisky ; 3, beer ; and 4, port wine. The quantity used in twenty-four hours represented between 75 and 80 c.c. of absolute alcohol. The result was a marked increase in the uric-acid excretion, the increase in most cases beginning in the second hour after the meal and reaching its height at the fifth hour ; this increase was not due to a hastening of the normal output, but was an actual increase in the amount produced. The effect, Chittenden believes, is doubtless due to a disturbance in the metabolism of the purin-bases of the food (p. 434). As already stated (p. 157) Hall has obtained purin-bodies from beer and porter.

**Absorption of Alcohol from the Stomach.**—Chittenden's experiments, in which 200 c.c. of 37 per cent. alcohol were introduced into the stomach of a dog with the duodenum ligated at the pylorus, resulted in the complete disappearance of the alcohol in 3–3½ hours by absorption through the stomach-walls into the blood. When the intestine is open the absorption is more rapid. When 6–8 grams of alcohol, as wine or beer, are taken into the stomach, 80–90 per cent. will have disappeared from the alimentary tract within ½ hour. In one of Chittenden's experiments 50 c.c. of 20 per cent. alcohol were absorbed within ½ hour. His conclusion is that, "in view of this rapid disappearance of alcohol from the alimentary tract, it is plain that alcoholic fluids cannot have much, if any, direct influence upon the secretion of either pancreatic or intestinal juice."

We have seen that when alcohol is taken into the stomach it



produces an increased secretion of an active gastric juice. When this stimulation is excessive changes are set up in the mucous membrane, as a result of which the gland tissue becomes less, and the secretion is correspondingly diminished. Up to the point where the stimulation resulting in increase of the normal secretion ends and the pathologic changes begin, alcohol is not injurious, but manifestly in health no such artificial stimulus is needed. So long as the individual is well, the natural food is a sufficient stimulus to the gastric glands and the additional stimulation of alcohol is uncalled for, and inasmuch as the exact line of demarcation between the amount of alcohol that does good and that which does harm has not as yet been absolutely determined, there is always a possibility that an excess may be taken and injury result. So far as the stomach is concerned, then, there is in a condition of health no useful purpose served by alcohol, but there are conditions in which this property of alcohol of exciting the gastric glands to increased activity may be availed of under medical advice.

Alcohol being a very diffusible substance, is mostly absorbed by the blood-vessels of the stomach, which carry it into the portal vein, and by this channel it reaches the liver, where its stimulating action is again exercised upon the cells of that organ, and an increased production of bile is the result. If, however, this stimulation is excessive and long continued, degenerative changes take place by which the organ ultimately becomes diminished in size and incapable of performing its function.

From the liver the blood carries the alcohol to the heart, which is quickened in action, and to the brain, whose activity is also increased. If the quantity of alcohol is excessive, the cells of gray matter in the brain are over-stimulated and great excitement results, and this may, if the quantity is sufficient, result in a suspension of the functions of the brain and a condition of unconsciousness, passing on in extreme cases to a fatal termination. But if the quantity of alcohol which reaches the brain is not enough to produce the fatal result, but still enough to maintain the condition of over-stimulation, there result changes in the structure of the brain, as there do in that of the stomach and liver, which weaken the mental activities and produce the irregular and inco-ordinated muscular movements so familiar to all who have observed individuals who have for years been addicted to drink.

From this necessarily incomplete recital of the effects of alcohol we now turn to some experimental evidence bearing upon the subject. These experiments have been carried on by various experimenters, and some of the results are well summarized in the following quotation from *An American Text-Book of Physiology* under the title "Alcohol in the Body." "Alcohol in the stomach at first prevents the gelatinization necessary in proteid for peptic

digestion, but this difficulty is of no great moment because the absorption of alcohol is rapid and complete. It makes the mucous membrane hyperemic, promotes the absorption of accompanying substances (sugar, peptone, potassium iodid), and stimulates the flow of the gastric juice. In this matter it acts as do other condiments (salt, pepper, mustard, peppermint), but if there be too great an irritation of the mucous membrane there is less activity (dyspepsia). The rapid absorption gives to alcohol its quick recuperative effect after collapse, and its value in administering drugs, especially antidotes. Alcoholic beverages combining alcohol and flavor promote gastric digestion and absorption, but often stimulate the appetite in excess of normal requirements. Alcohol is burned in the body, but may also be found in the breath, perspiration, urine, and milk. Alcohol has no effect on proteid decomposition, but acts to spare fat from combustion. The addition of 50 to 80 grams of alcohol to the food has no apparent effect on the nitrogenous equilibrium. Alcohol in the body acts as a paralyzant on certain portions of the brain, destroying the more delicate degrees of attention, judgment, and reflective thought, diminishing the sense of weariness (use after great exertion—furnished to armies in the last hours of battle), and raising the self-esteem; it paralyzes the vasoconstrictor nerves, producing turgescence of the skin with accompanying feeling of warmth, and thereby indirectly aiding the heart. Alcohol acts to stimulate the respiration, especially in the tired and weak, wine with a rich bouquet, like sherry, being more effective than plain alcohol. The higher alcohols, propyl, butyl, amyl, are more poisonous as the series ascends, and are less volatile, less easily burned, and therefore more tenaciously retained by the body, with more pernicious results."

The most complete and the most recent knowledge which we possess on the subject of alcohol and its effects upon the human body is contained in a publication entitled "Physiological Aspects of the Liquor Problem, Investigations made under the Direction of W. O. Atwater, John S. Billings, H. P. Bowditch, R. H. Chittenden, and W. H. Welch, Sub-Committee of the Committee of Fifty to Investigate the Liquor Problem," which was issued from the press in 1903. The only portion of this report to which it is our purpose to here refer is that which treats of "The Nutritive Value of Alcohol," by Prof. W. O. Atwater. The author states at the outset that no one doubts that the continued and excessive use of alcohol is injurious to body, mind, and character, and that in large enough quantities it is really a poison. He, however, makes the broad statement that the great majority of physiologists and hygienists hold to the opinion that alcohol, taken in small quantities, may serve the body for nutriment, that it is at some times valuable, at others harmful.

The two chief functions of food are, Prof. Atwater states, to



furnish materials for the growth and repair of the tissues and fluids of the body and to yield energy for maintaining the healthful bodily temperature and for its muscular work. The proteids in the main perform the former function, and while they also yield energy, yet this is principally due to the fats and carbohydrates. Alcohol, containing no nitrogen, is not a tissue builder, its value to the body, therefore, if it possesses any, must be that of a fuel, supplying energy. Food serves as fuel by being oxidized in the body; in this oxidation potential energy becomes kinetic; part of this kinetic energy appears as heat and another part as muscular work. Besides, in supplying energy the foods protect the body from consumption, for energy must be produced, and if there is nothing else to produce it from, the body tissues must undergo oxidation. The question, then, which Prof. Atwater proposed to settle was: "Is the energy of alcohol transformed like that of ordinary food materials?"

In determining this question a respiration calorimeter was used; this served to measure the materials received and given off from the body, including the products of respiration, and also to measure the heat given off by the body.

In conducting the experiments pure ethyl alcohol was used, generally to the amount of two and one-half ounces a day, about as much as would be contained in a bottle of wine with 10 per cent. alcohol, or three or four glasses (6 or 8 ounces) of whisky. In some of the experiments whisky or brandy was used. The alcohol given was divided into six doses—three given with meals and three between meals—the object being to avoid any special influence of the alcohol upon the nerves, and thus test its action as food under normal bodily conditions.

Without dwelling further upon the experiments we will quote the results:

1. Alcohol in moderate amounts tended to very slightly increase the digestibility of the protein, but did not materially alter the digestibility of the other nutrients. While this is the statistical result of these experiments, the extent to which it would be true in general experience is by no means certain.

2. In the average of the experiments at least 98 per cent. of the alcohol taken was actually oxidized in the body. Other experiments show that in ordinary diet about 98 per cent. of the carbohydrates, 95 per cent. of the fats, and 93 per cent. of the protein are burned in the body. Accordingly, the alcohol is more completely oxidized than are the nutrients of an ordinary mixed diet.

3. The law of the conservation of energy obtained with the alcohol diet as with the ordinary diet. The potential energy of the alcohol oxidized in the body was transformed completely into kinetic energy and appeared either as heat or as muscular work, or both. To this extent, at any rate, it was used like the energy of the protein, fats, and carbohydrates of the food.

4. Fat protection in the alcohol rations was very slightly different from that with the ordinary rations; in other words, the alcohol was practically as efficient in the protection of body fat from consumption as the fats or carbohydrates of the food which it replaced.

5. The power of alcohol to protect the protein of food or body tissue, or both, from consumption is clearly demonstrated. Its action in this respect appears to be similar to that of the carbohydrates and fats; that is to say, in its oxidation it yields energy needed by the body, and thus saves other substances from oxidation.

6. Alcohol appears to exert at times a special action as a drug. In large quantities it is positively toxic and may retard or even prevent metabolism in general, and proteid metabolism in particular. In small doses it seems at times to increase the disintegration of protein. The only justification for calling alcohol a proteid poison is found in this disintegrating tendency.

7. In some of the experiments alcohol was administered with coffee, in others with water. There was no direct evidence that the coffee interfered with the action of the alcohol; if any effect was produced, it was to increase rather than retard proteid metabolism.

8. When 72 grams of alcohol, given in six doses and furnishing 500 calories of energy, replaced the isodynamic amounts of fats and carbohydrates, the alcohol caused no considerable increase in the amount of heat radiated from the body. If the alcohol had all been taken at one dose, it might have caused the cutaneous vessels to dilate, possibly stimulated the sweat-glands, increased the circulation, and thus increased the heat radiation. If enough alcohol had been taken to induce the comatose condition called "dead drunk," and if the men experimented upon had been exposed at the same time to severe cold, the production of heat in the body might have been retarded and the radiation increased so as to lower the body temperature by several degrees.

9. In the experiments alcohol was not suddenly or rapidly oxidized, or if there was such rapid oxidation, there was a corresponding decrease in the oxidation of carbohydrates, fats, or protein. The alcohol, carbohydrates, and fats replace one another as sources of energy; as either was oxidized, the others were proportionately spared.

10. In all the test experiments alcohol was certainly, and in the work experiments it was in all probability, a source of heat for the body.

11. The hypothesis that alcohol contributed its share of energy for muscular work is natural and extremely probable, but not absolutely proved. Even with the small doses in these experiments there were indications that the subjects worked to slightly better advantage with the ordinary rations than with the alcohol. The

results of practical tests on a large scale elsewhere coincide with those of general observation in implying that the use of any considerable quantity of alcoholic beverages as part of the diet for muscular labor is generally of doubtful value and often positively injurious.

In closing the consideration of the question "Is alcohol food?" Prof. Atwater says: "If I may be permitted the expression of a personal opinion it is that people in health, and especially young people, act most wisely in abstaining from alcoholic beverages, but I cannot believe that the cause of temperance in general, or the welfare of the individual, is promoted by basing the physiologic argument against the use of alcohol on anything more or less than attested fact."

If, with the results of these experiments in mind, we now turn back to the definition of food, we shall see that alcohol is a food. We have dwelt to a considerable extent upon this subject for the reason that many of the text-books used in the grammar and high-schools of the country deal with the effects of alcohol upon the human body by reason of laws which have been enacted requiring them so to do. Unfortunately, many of these books do not represent the physiologic facts as we believe them to be. The tendency of these books, to say the least, is to teach that alcohol is not a food, but a poison. That it is a food we think has been abundantly proved; that it is a poison is also true, but whether it is the one or the other depends upon the amount taken. There are many things which, in certain quantities, are not only not harmful, but are absolutely essential. The process of stomach digestion requires that the gastric juice should contain hydrochloric acid, and normally this is present to the amount of 0.2 per cent., and yet given in a sufficiently large quantity it would produce death.

The experiments of Prof. Atwater and his colleagues mark a new era in the history of this most important subject, the effect of alcohol upon the human body; and in all future discussions arguments should not be based upon the experiments which preceded theirs, unless they were conducted with similar precautions.

### III. NUTRITIVE FUNCTIONS.

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#### DIGESTION.

HAVING considered the composition of the body and food, there may now be taken up the study of the nutritive functions.

As has been noted already, the body is constantly producing *energy* and undergoing *waste*, both of which require the taking of food. But food is of absolutely no use to the body until it reaches the blood and by this fluid is conveyed to the tissues. So long as the food remains within the alimentary canal it is as much outside the body, so far as nutrition is concerned, as if it had never been taken inside. To be of any service the food must enter the blood, and it does this by being *absorbed*.

In some forms of animal life the food is of such a nature that it readily and without further change undergoes absorption—that is, passes through the walls of the absorbing vessels. In other forms of animal life this is not the case: in the latter, unless certain changes take place, the food passes out of the alimentary canal as waste material, without having contributed to the nutrition of the body in the slightest degree. Unless, therefore, some provision was made to obviate this, such animals would die of starvation. The provision which has been made consists in the presence of certain organs whose duty is to change the form of the food-substances from that in which they will not, into that in which they will, be absorbed; and into such forms that when they reach the tissues they can be utilized by them. It is this preparation for absorption which constitutes digestion, and the organs concerned in bringing about the necessary changes in the food are the digestive organs.

Manifestly, these organs will be simple or complex according to the amount of change which it is necessary to bring about in the food in order that absorption may take place. Thus, if the food on which an animal relies for its sustentation is already in a proper form, no change will be needed, and the animal will therefore have no digestive organs. If the requisite change is a slight one, the number of the digestive organs will be few and their structure

will be simple. But if the food is varied in its composition, and largely made up of food-stuffs that require many changes before they are fitted for absorption or before they can be utilized by the

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FIG. 92.—General scheme of the digestive tract, with the chief glands opening into it.

tissues after they are absorbed, then the digestive apparatus—that is, the group of organs concerned in digestion—will be complex. Such is the character of the food of man, and, consequently, such is the character of his digestive apparatus (Fig. 92).

The human digestive apparatus consists of the *alimentary canal* and the other *digestive organs*, which, although outside, still communicate with this canal by ducts through which their secretion is poured. The alimentary canal consists of the *mouth*, the *esophagus*, the *stomach*, and the *small intestine*. The digestive organs which are outside, but which discharge their secretion

into this canal, are the *salivary glands*, the *liver*, and the *pancreas*.

The digestive process is subdivided into three parts: That which takes place in the mouth—*mouth digestion*; that which takes place in the stomach—*stomach* or *gastric digestion*; and that which takes place in the small intestine—*intestinal digestion*. Formerly, when digestion was spoken of it was always stomach digestion which was referred to, because it was supposed that the entire process took place in that organ; and when digestion was impaired the remedies which physicians employed were directed to the stomach alone. There is, unfortunately, too much of this kind of practice even now; but the study of physiology has taught that indigestion may be due quite as much to the improper performance of mouth and intestinal digestion as to that which takes place in the stomach, and unless this is recognized many cases will be unsuccessfully treated.

When food is taken into the mouth it has, presumably, been as fully prepared as possible by the removal of those portions which are of no nutritive value. No one eats the husks of corn, the shells of nuts, the gristle of meat, or similar substances, because experience has shown that they are of little or no nutritive value, and that their digestion is practically impossible. Such extraneous matters, therefore, are removed, and the food is further prepared, provided this preparation is necessary, by the process of cooking. In the form, then, in which the food is taken in it is as fully prepared as it can be outside the body. Whatever remains to be done in order that the food may be prepared for absorption must be effected after it enters the alimentary canal.

Some of the ingredients of human food are already in a condition to be absorbed by the blood-vessels of the alimentary canal, and therefore they need to undergo no change. Such ingredients are water, salts, and dextrose; and were they the only constituents of the food, no digestive organs would be needed; but, as already said, this is not the fact. The greater part of the food must be changed before it can be absorbed. The first step in this conversion is that which takes place in the mouth.

### MOUTH DIGESTION.

When food enters the mouth it consists of a mixture of various food-stuffs. In order that the changes which these food-stuffs undergo may be traced thoroughly, let it be supposed that representatives of all classes of food-stuffs are present, namely, (1) *inorganic*, salts and water; (2) *carbohydrates*, starch and sugar; (3) *fats*, or oils; and (4) *proteids*.

All the food of a fluid nature, no matter what classes of food-

stuffs it comprises, passes immediately from the mouth into the pharynx, and thence through the esophagus into the stomach.

FIG. 93.—Schema showing the temporary and permanent teeth in a child five years old (right side): 1, temporary teeth of the upper jaw; 2, the five temporary teeth of the lower jaw; 3, 3', permanent median incisors; 4, 4', permanent lateral incisors; 5, 5', permanent canines; 6, 6', the four permanent bicusps; 7, 7', first molar; 8, second molar of lower jaw in its alveolus (in the upper jaw the second molar is not yet formed); 9, inferior dental canal; 10, orifice of inferior dental canal (after Teetut).

Such food undergoes no chemical changes whatever during this time; thus, milk, chocolate, and beverages of various kinds are unchanged. If, however, fluids are taken into the mouth when it contains solid food, the latter will be softened by them, and the

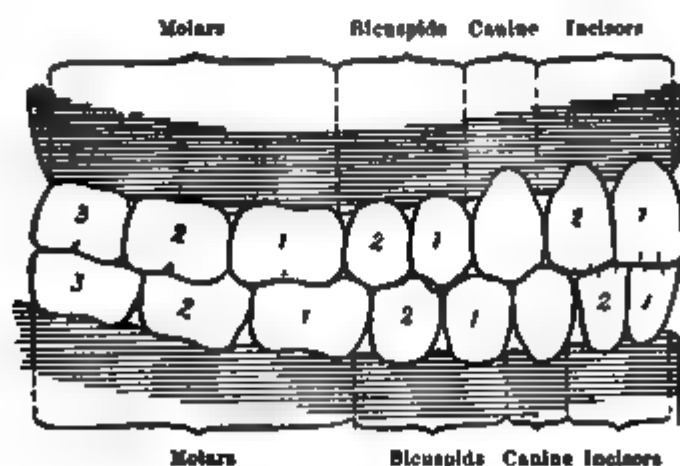


FIG. 94.—Schema of the two dental arches; view of their external faces, showing their natural relations.

two will be mixed, and will come under the influence of the agents concerned in carrying on mouth digestion. These agents are the *teeth* and the *salivary glands*.

**Mastication.**—The chewing of the food or mastication is performed by the teeth.

The first set of teeth, which are known as *temporary, deciduous, or milk-teeth* (Fig. 93), and which exist during early childhood are twenty in number, and the second or *permanent* set (Fig. 95), which begin to take the place of the first set at about the sixth year of life, remain to a greater or lesser extent until old age. The latter set is composed of thirty-two teeth—four *incisors*, two *canines*, four *bicus-pids*, and six *molars*—in each jaw (Fig. 95). The incisors, or cutting teeth, are adapted to bite the food; the molar teeth, or grinders, are adapted to grind the food, while the canines and bicuspid in man aid the incisors and molars. In the carnivora, the canines—or tushes as they are called—are very long and pointed, and are admirably adapted to pierce the body of their prey, even to the vitals, thus killing and subsequently tearing the animal preparatory to feeding upon it. The herbivora need no such aggressive weapons, and in them the molars are so constructed as to grind the food, their teeth resembling the grindstones of the miller. The teeth of man have characters which resemble those of both carnivora and herbivora, and from this fact it may be inferred that it was designed that man should have a mixed diet.

**Movements of Mastication.**—The movements concerned in mastication are those of the lower jaw upon the upper, produced by the action of the following muscles: *Masseter, temporal, internal and external pterygoids, digastric, mylohyoid, and geniohyoid*. The lower jaw is brought against the upper by the contraction of the masseters, temporals, and internal pterygoid muscles. The action of the external pterygoids, when both are acting, is to draw the lower jaw forward, causing it to project beyond the upper. If but one external pterygoid acts, that side of the jaw is drawn forward and the chin deviates to the opposite side.

FIG. 95.—The palate and superior dental arch (right side): 1, median incisors; 2, lateral incisors; 3, canine; 4, first bicuspid; 5, second bicuspid; 6, first molar; 7, second molar; 8, wisdom-tooth; 9, mucous membrane of the hard palate continuous behind with that of the soft palate; 10, the anteroposterior raphe of palate; 11, pits on each side of the raphe perforated with the orifices of glands; 12, anterior rugosities of the mucous membrane (after Testut).



The digastric, mylohyoid, and geniohyoid muscles depress the lower jaw, and this is an essential part of mastication, for the jaws must be separated as well as brought together to make the act complete.

The movements of the jaw are a combination in which these muscles act, sometimes grouped in one way and sometimes in another. The *buccinator muscles* in the cheeks and the muscles of the *tongue* assist very materially by keeping the food between the teeth, where it may be comminuted and triturated.

The function of the teeth in man is to *subdivide* and *commminute* thoroughly the food; and this function is an essential part of the process of digestion. As will be seen later, during digestion certain fluids are poured into the alimentary canal to contribute their part toward the process. These fluids cannot act properly on large, compact masses of food. While their action is not that of solution, still, in order to fulfil perfectly their office, they must come in direct contact with every portion of the food. This contact is the more essential because the given time in which to act is not unlimited, and if the process is not completed within the allotted time, digestion will be performed incompletely. When a chemist desires to dissolve a substance quickly and completely, he first pulverizes it in a mortar. Likewise, in digestion one of the most important steps is this process of comminution or mastication. If mastication is insufficiently performed, the succeeding steps in the process of digestion are seriously interfered with, and indigestion or dyspepsia results.

Insufficient mastication is one of the commonest causes of indigestion, and many dyspeptics are drugged with remedies prescribed to overcome some fancied trouble in the stomach, when they should be sent to a dentist. Defective mastication may be due to various causes. The teeth may be so decayed as to expose sensitive surfaces, and when food which is at all hard is taken into the mouth the discomfort, or sometimes the pain, caused their possessor in chewing it makes the performance of the act incomplete, and the food is swallowed half-masticated; or the eater may be in too great a hurry and not give enough time to this important act. Whatever the cause, the result is the same; therefore too much attention cannot be given to this process, which is so simple as often to be overlooked.

**Insalivation.**—Coincident with mastication is the act of *insalivation* or the incorporation of saliva with the food. Saliva is the mixed secretion of the salivary glands, which comprise the two *parotids*, the two *submaxillaries*, and the two *sublinguals*, together with the buccal glands of the mucous membrane of the mouth (Fig. 96).

**Physiologic Anatomy of the Salivary Glands.**—The *parotid* gland is the largest of all the salivary glands, and is named from

its proximity to the ear, lying below and in front of it. Inflammation of this gland is *parotitis* or *mumps*. Its secretion passes out by *Stenson's duct*, which is about 6 cm. long and the size of a crowquill, and is discharged into the mouth on the inner surface of the cheek, opposite the second molar tooth of the upper jaw.

FIG. 96.—View of the salivary glands (right side) (the inferior maxilla has been removed from the symphysis to the ascending ramus): *A*, parotid gland, with *A'* its anterior prolongation; *B*, submaxillary gland; *C*, sublingual gland; *D*, gland of Nuhn or of Blandin; *E*, gland of Weber. *a*, duct of Steno; *b*, duct of Wharton with *b'* its orifice on the floor of the mouth; *c*, excretory ducts of the sublingual gland. 1, sternocleidomastoid; 2, posterior belly of the digastric; 3, 3', mylohyoid, right and left; 4, hyoglossus; 5, genioglossus; 6, pharyngoglossus; 7, geniohyoid muscle; 8, masseter; 9, buccinator; 10, middle constrictor of the pharynx; 11, primitive carotid; 12, internal jugular vein; 13, external carotid artery; 14, lingual artery; 15, facial artery; 16, facial vein; 17, superficial temporal artery; 18, transverse facial artery; 19, facial nerve; 20, auriculotemporal nerve; 21, lingual nerve, displaced slightly upward on account of the position of the tongue.

The nerves which supply this gland are branches of the carotid plexus of the sympathetic, the facial, the auriculotemporal, and the great auricular nerve.

The *submaxillary* gland is situated beneath the lower jaw. Its secretion is discharged by *Wharton's duct*, which is about 5 cm.

long and opens at the side of the frenum of the tongue. Its nerves come from the submaxillary ganglion, and consist of filaments of the chorda tympani of the facial and lingual branch of the inferior maxillary, of the mylohyoid branch of the inferior dental, and of the sympathetic.

The *sublingual* gland lies under the mucous membrane, at the side of the frenum of the tongue. Its secretion is discharged through from eight to twenty ducts, *ducts of Rivinus*, which open on the prominence of the mucous membrane made by the gland beneath. Sometimes two or more of these ducts join, and form the *duct of Bartholin*, which opens into Wharton's duct. The nerves of this gland are branches of the lingual.

Besides these three sets of glands there are numerous mucous glands on the dorsum and the edges of the tongue, in the tonsil, and the soft palate, whose secretion is a constituent of the saliva.

The salivary glands belong to the class ordinarily described as *compound racemose glands*. Inasmuch, however, as the secreting portions are not sacs, which are characteristic of racemose glands, but tubes, this variety of gland is perhaps better denominated *compound tubular*. It consists of lobes, which in turn are made up of lobules, each of which is composed of tubular alveoli or acini connected with a duct. The ducts from different lobules join together to form larger ducts, and finally all combine to form the main duct of the gland.

*Mucous* (Fig. 97) and *Albuminous Glands*.—Two types of glands are recognized by histologists according to the product and the appearance of the cells within the alveoli of the salivary glands: *mucous* and *albuminous* or *serous*.

The mucous gland secretes a tenacious fluid containing mucin, and the cells are relatively large and clear, and have been described as resembling ground glass; their granules are ordinarily indistinct.

FIG. 97.—Mucous gland: submaxillary of dog; resting stage.

The sublingual and the mucous glands of the mouth are representatives of this type.

These glands also contain *demitunes of Heidenhain* or crescentic cells, which are placed between the mucous cells and the basement-membrane (Fig. 97). Heidenhain, whose name they bear,

considers them to be undeveloped mucous cells, destined to replace the secreting cells when they shall have ceased to perform their function and have disappeared; while other opinions are that they are a distinct type of albuminous cell, or are due to a post-mortem change. Some observers claim to have demonstrated that the lumen of the albuminous glands is continued as fine capillary spaces between the cells of these glands, and that from these pass off smaller branches which penetrate the cells themselves, and that in the mucous glands these same capillaries exist only in connection with the demilunes. If this is confirmed, it would seem to be more than probable that the demilunes have distinct secretory functions.

The albuminous gland secretes a watery or serous fluid, which

FIG. 98.—Parotid of the rabbit, in the resting condition (after Heidenhain).

contains, besides water, inorganic salts, some albumin, and may also contain enzymes. The cells of this variety are small and compactly fill the alveoli, leaving but little lumen (Fig. 98). They contain albuminous granules which are very distinct. The parotid gland represents the serous or albuminous type.

The human submaxillary gland is a mixed type containing both mucous and albuminous alveoli, the latter, however, in greater number.

It is a fact that in mucous glands some cells are found which are regarded as characteristic of the albuminous type, and vice

*versa*; so that it has been suggested that it would be better to apply the terms mucous and albuminous to the cells, rather than to the glands.

*Secretory Nerves of the Salivary Glands.*—The relation existing

*A**B**C**D*

FIG. 99.—Parotid gland of the rabbit in a fresh state, showing portions of the secreting tubules: *A*, in a resting condition; *B*, after secretion caused by pilocarpin; *C*, after stronger secretion—pilocarpin and stimulation of sympathetic; *D*, after long-continued stimulation of sympathetic (after Langley).

between nerves and the secretion of saliva has been more carefully investigated in dogs and rabbits than in man, and it is to the result of these investigations that we shall especially refer.

Con-  
nective  
tissue.

— Intralobu-  
lar duct.

Gland-cell  
of acinus.

— Interme-  
diate  
duct.

FIG. 100.—Section from parotid gland of man (Böhm and Davidoff).

The nervous supply of the parotid gland is derived from: (1) The glossopharyngeal nerve, through its tympanic branch of the nerve of Jacobson, the small superficial petrosal nerve, the otic

ganglion, and finally the auriculotemporal branch of the inferior maxillary division of the fifth nerve or trigeminus. This is shown in Fig. 101. (2) The cervical sympathetic, which is distributed principally to the walls of the blood-vessels, although some of its fibers, in some animals at least, are secretory.

The nervous supply of the submaxillary and sublingual glands, like that of the parotid, is also double, the chorda tympani, a branch of the seventh or facial, and branches of the sympathetic plexus around the facial artery, being the nerves supplying these glands. There is excellent authority for the statement that the chorda tympani is in reality a branch of the glossopharyngeal which joins the facial in the tympanum. The chorda tympani joins the lingual nerve for a part of its course, and then leaves it to pass through the so-called submaxillary ganglion to the glands. It has been suggested that this would be more properly called the sublingual ganglion, inasmuch as only those fibers which are distributed to the sublingual gland are in communication with the nerve-cells of this ganglion, while those which pass to the submaxillary gland connect with a collection of nerve-cells in that gland, *Langley's ganglion*. The course of the chorda tympani is shown in Fig. 102.

**Effect of Stimulation of the Chorda Tympani and Sympathetic Nerves.**—If the chorda tympani of a dog is stimulated by passing through it weak induction shocks, the submaxillary gland secretes more saliva. The small arteries of the gland are dilated and a larger amount of blood passes through the gland, giving it a distinctly reddish appearance. Stimulation of the sympathetic fibers produces a diminution in the secretion, and the reddish color disappears, leaving the gland pale, a change evidently due to a constriction of the blood-vessels. It might at first seem that the increase in the amount of blood caused by the stimulation of the chorda tympani would explain the increased secretion of saliva by filtration of the fluid of the blood through the vessel-walls, but experiments have shown that there are in this nerve true secretory fibers—*i. e.*, fibers which carry impulses to the secretory structure of the gland, and that the cells are directly stimulated to increased action. We may briefly refer to three of these experiments: 1. If the blood-supply of the gland is cut off, and the chorda tympani stimulated, the secretion of saliva will still be increased. 2. If atropin is injected into the animal and the chorda tympani then stimulated, the blood-vessels will be dilated, but there will be no secretion. 3. If hydrochlorate of quinin is injected into the gland, the blood-vessels dilate, but no secretion follows. It will be seen from these experiments that two effects are produced by stimulation of the chorda tympani: 1. A dilatation of the blood-vessels; and 2. A direct stimulation of the cells. From this it is evident that there are two sets of fibers in this nerve,

each having a distinct function; one *vasodilator* and the other *secretory*. There are also two sets of fibers in the sympathetic nerves which supply these glands: One *vasoconstrictor*—i. e., when

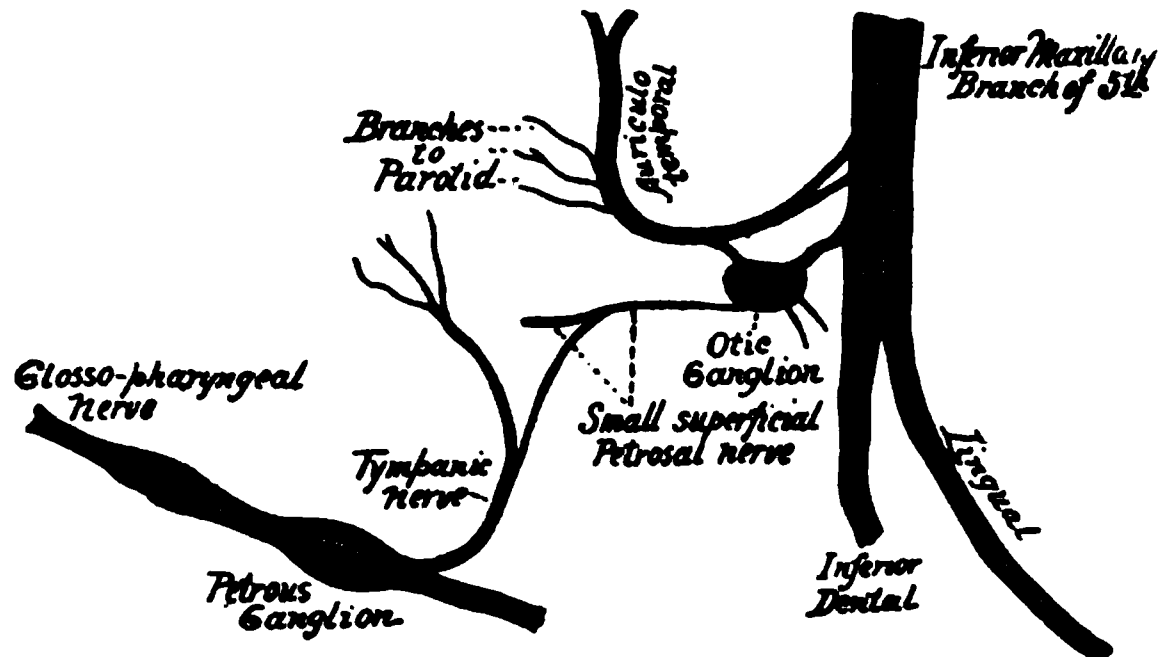


FIG. 101.—Schematic representation of the course of the cerebral fibers to the parotid gland.

stimulated the blood-vessels are constricted; and the other *secretory*. It is, however, mainly through the chorda tympani that the impulses pass which cause secretion.

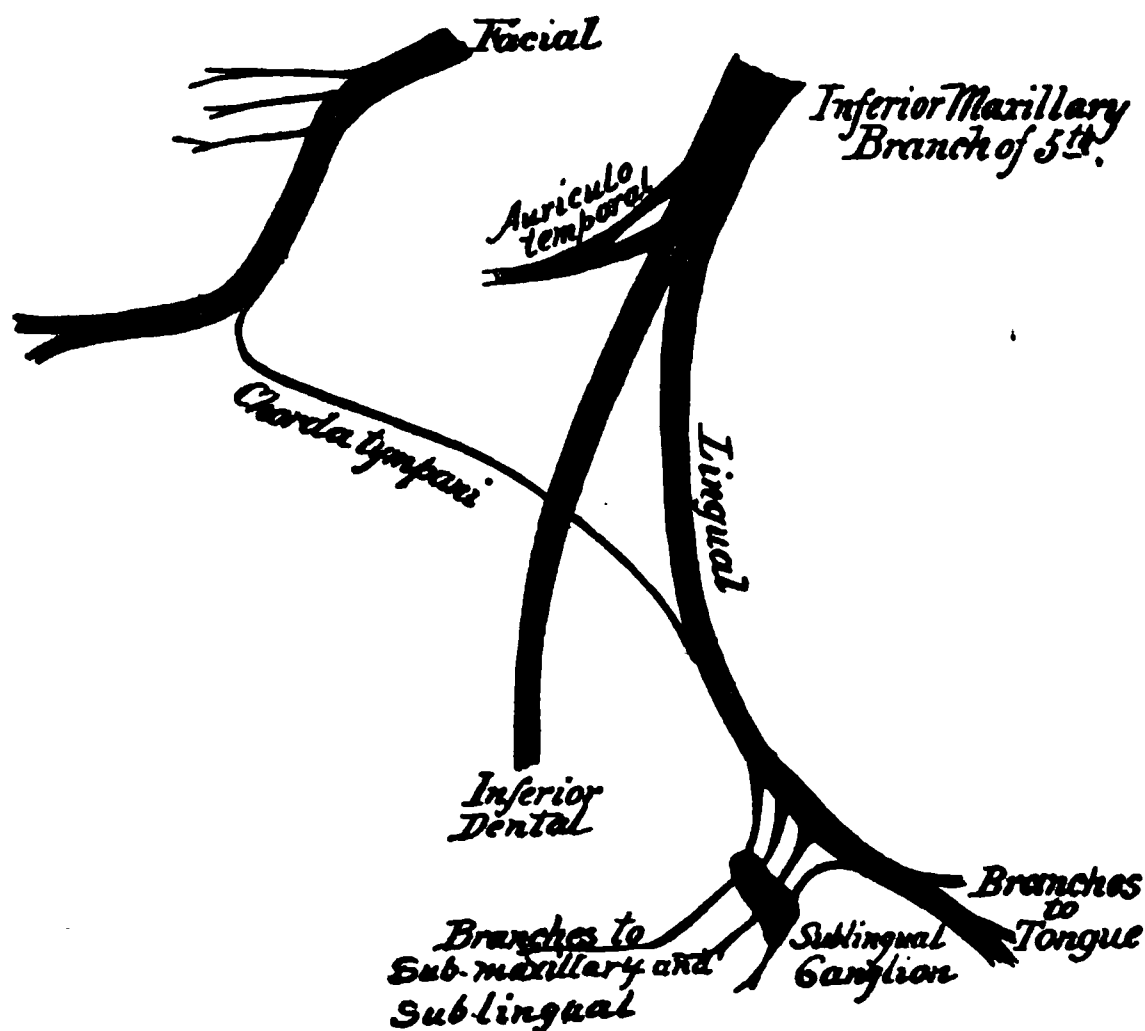


FIG. 102.—Schematic representation of the course of the chorda tympani nerve to the submaxillary gland.

The glossopharyngeal fibers, which have already been traced to the parotid gland, convey the impulses which cause secretion in this gland. The sympathetic nerves are vasoconstrictor in function.

From the mass of evidence which has been accumulated, to only a small part of which have we made reference, it is indisputably proved that there are true secretory fibers distributed to the salivary glands; and the same is true of other glands as well, such as the lachrymal, perspiratory, and gastric glands; but the method by which these fibers terminate is not so certain, though it appears probable that it is by forming plexuses between and around the secreting cells. Further than this, it is more than probable that there are two kinds of secretory fibers: One which transmits impulses that cause the secretion of the organic constituents of the saliva, and called *trophic*; the impulses conveyed by the other, the secretory fibers proper, producing the secretion of the water and the inorganic salts of the saliva.

**Paralytic Secretion.**—If the chorda tympani is cut, there is no immediate effect, but after a day or two the gland begins to secrete a very watery saliva which continues for several weeks, and then it atrophies. This secretion is called *paralytic*. Although the section is made on but one side, both glands are similarly affected, and the secretion on the opposite side to the section is called *antiparalytic* or *antilytic*. There are two explanations given to account for this phenomenon. One is that the continuous secretion is due to an increased irritability of the secretion-center in the medulla oblongata and of the nerve-cells in the gland, by which the venous condition of the blood is alone sufficient to cause them to send out continuous impulses to the secreting cells. The other theory is based upon the fact that katabolic changes are going on in the cells of the gland which are inhibited by impulses coming through the chorda tympani; if, therefore, this nerve is cut, such impulses no longer restrain the katabolic changes, and they go on without interference, with the result of atrophy of the gland and the formation of the paralytic secretion.

FIG. 103.—A number of alveoli from the submaxillary gland of dog, stained in chrome-silver, showing some of the fine intercellular tubules (Huber).

**Secretion of Saliva.**—The secretion of saliva is normally a reflex act. It is ordinarily brought about by the stimulation of the mucous membrane of the mouth by sapid substances—that is, those which excite the sense of taste, although chemical and even mechanical stimuli will produce the same result. The chewing of a piece of rubber will cause a profuse flow of saliva. The



glossopharyngeal and lingual nerves serve as the afferent nerves in this act, carrying the impulses to a center in the medulla, from which efferent impulses pass out through the secretory nerves to the glands. This center may be stimulated by afferent impulses reaching it through other nerves; thus salivary secretion may be increased, or "the mouth made to water," by the smell or even the thought of food. This center may also be inhibited from sending out secretory impulses, as through fright or other nervous disturbance, thus diminishing the secretion of saliva and causing the dry mouth and throat which so commonly accompany such conditions.

**Changes in the Salivary Cells.**—Certain changes take place in the salivary cells as a result of their activity. When a rabbit is fasting, the cells of the parotid gland are granular throughout, their outlines being faintly marked by light lines. If it is fed, or pilocarpin injected, or the sympathetic stimulated, the granules disappear from the outer portion of the cells, so that there is an external clear border surrounding the granular interior. If the stimulation continues, the granules diminish and are collected near the lumen of the alveoli and at the margin of the cells, the clear border becomes enlarged, and the cells become smaller. The explanation of this is that the granules contain a substance which is or which becomes the ptyalin of the saliva. If it should be demonstrated hereafter that there is a zymogen which precedes the ptyalin, it would receive the name of *ptyalinogen*, but this has not as yet been proved to occur. These granules in the cells are called zymogen granules. While these granules are being used up to form the ptyalin new material is being deposited by the blood at the base of the cells, which in turn will later form the zymogen or ptyalin.

Similar changes take place in the mucous glands, in the cells of which are granules (125 to 250 to a cell) composed of *mucinogen*, which becomes *mucin*, and is in this form discharged into the lumen of the alveoli. The demilunes, before referred to, are situated outside these cells which produce the mucinogen.

**Properties and Composition of the Saliva.**—The secretion of the human *parotid* gland is a clear fluid, though sometimes turbid, and contains some epithelial cells. It is alkaline in reaction, but less so than the saliva of the submaxillary gland. Its specific gravity is very variable, as is shown by the following figures: Mitscherlich gives it as 1.006 to 1.008; Oehl, 1.010 to 1.012 with scanty, and 1.0035 to 1.0039 with plentiful secretion; Hoppe-Seyler, 1.0061 to 1.0088; the solids being from 5 to 16 parts per 1000. It contains ptyalin and potassium sulphocyanate, but no mucin.

The secretion of the human *submaxillary* gland is clear and watery, always alkaline, and has a specific gravity between 1.0026

and 1.0033. The solids are from 3.6 to 4.6 parts per 1000. It contains ptyalin, but authorities differ as to its containing potassium sulphocyanate.

The existence of such ducts as those of Stenson and Wharton makes it easy to obtain the pure secretions of the parotid and submaxillary glands by the introduction into them of cannulæ; but this is not true of the *sublingual* gland, hence the secretion from this gland in man has never been obtained in sufficient quantity to make a thorough analysis of it, but it is known to be more alkaline than that of the submaxillary, to contain mucin, a diastatic enzyme, and potassium sulphocyanate.

The secretion of the *mucous* glands of the human mouth has never been obtained pure, or in quantity sufficient to analyze. It is a tenacious and viscid secretion and alkaline in reaction.

*Mixed saliva*—i. e., the saliva as found in the mouth—the product of all the salivary glands, is a clear fluid, viscid in consistency, with a specific gravity between 1.002 and 1.008, alkaline in reaction, and containing from 5 to 10 parts per 1000 of total solids. It is secreted to the amount of between 300 and 1500 grams daily. Moore states that when it is acid this reaction is commonly due to fermentation of particles of food in the mouth. Many authorities state that it contains sodium carbonate, but Chittenden and Richards make the following statement: "Human mixed saliva contains normally no sodium carbonate whatever; the alkalinity indicated by litmus, lacmoid, etc., is due to hydrogen alkali phosphates, with possibly some alkali bicarbonate. Mixed saliva invariably acts acid to phenolphthaleïn.

"The alkalinity of mixed saliva, as indicated by lacmoid, is greater before breakfast than after the morning meal; a conclusion which stands in direct opposition to the statement frequently made that 'the alkalinity (of mixed saliva) is least when fasting, as in the morning before breakfast, and reaches its maximum with the height of secretion during or immediately after eating.'"

When saliva is examined under the microscope there are seen epithelial scales from the mucous membrane of the mouth, and leukocytes, probably from the tonsils and elsewhere, described usually as *salivary corpuscles*. Bacteria and portions of food are commonly found in saliva, but they are not constituent parts, but rather impurities.

Examined *chemically* the saliva is found to contain the enzyme *ptyalin*, *mucin*, and traces of *proteid*, probably of the nature of a globulin, but too little in amount to be quantitatively determined. It contains also, though not invariably, *potassium sulphocyanate*, which is regarded as a product of proteid metabolism; but with our present knowledge the physiologic value of this constituent is still undetermined.

The inorganic constituents of saliva are sodium chlorid, cal-

cium phosphate and carbonate, magnesium phosphate, and potassium chlorid. Although it is commonly stated that it contains also sodium carbonate, yet, as we have seen, this is denied by Chittenden and Richards, whose investigations are the most recent on this subject. Calcium carbonate and phosphate occasionally form *salivary calculi* in the glands or their ducts, and may require removal by the surgeon. These salts also contribute to the formation of the *tartar* on the teeth.

The following table gives four analyses of human mixed saliva, by as many chemists. It should be remembered, however, that even in the same individual the composition of this secretion varies during the day, and that, too, independently of the taking of food. Observation has shown that between 7 and 11 A.M., provided no food is taken, its composition is very constant.

Mixed Human Saliva.

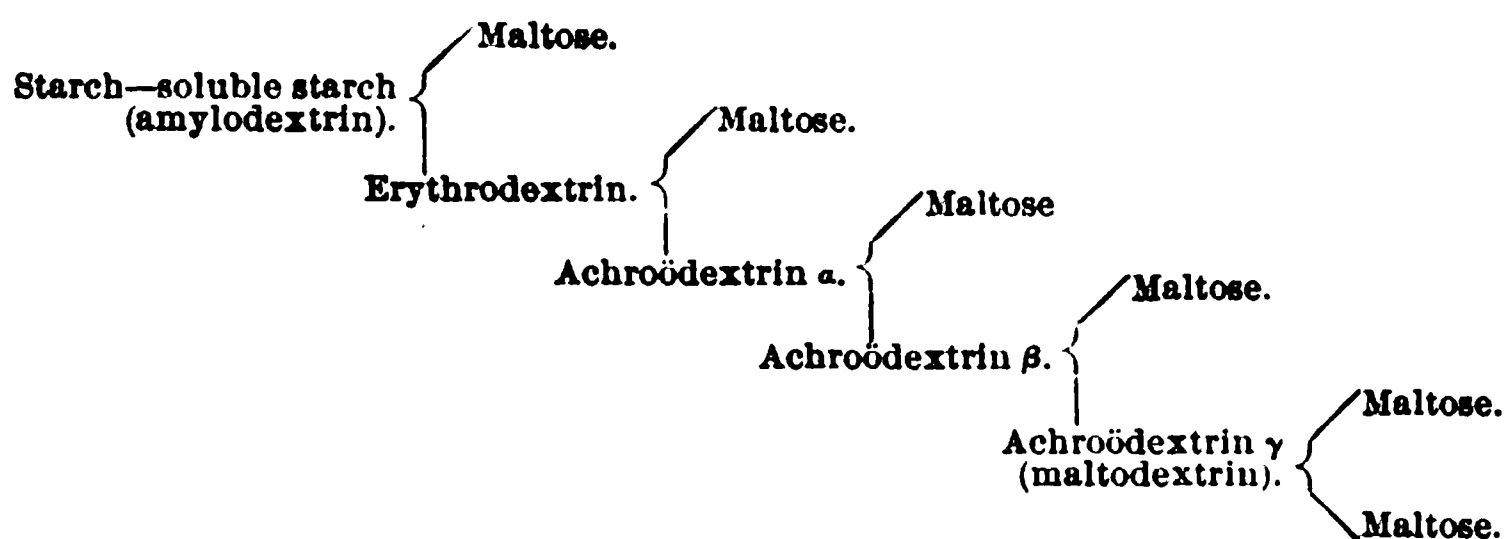
	I.	II.	III.	IV.
Water . . . . .	992.9	995.10	994.10	994.20
Total solids . . . . .	7.1	4.84	5.90	5.80
Suspended solids (epithelium, mucus, etc.) . . . . .	1.4	1.62	2.13	2.20
Soluble organic matter (ptyalin and albumin) . . . . .	3.8	1.84	1.42	1.40
Potassium sulphocyanate . . . . .		0.06	0.10	0.04
Inorganic salts . . . . .	1.9	1.82	2.19	2.20

**Office of Saliva.**—This is twofold : (1) chemical and (2) mechanical.

The *chemical action of saliva* is due to the enzyme *ptyalin*, which is undoubtedly the most important constituent of the mixed saliva. This ingredient exists in the human parotid gland at birth, but does not appear in the submaxillary gland until the age of two months. It is an *amylolytic* or *diastatic* enzyme—*i. e.*, one having the property of changing starch into sugar. Although it resembles diastase, which is the enzyme obtained from malt, in its power to convert starch, still the enzymes are not the same. Thus, the optimum temperature for ptyalin is 46° C., and its power is destroyed between 65° C. and 70° C.; while the optimum temperature for diastase is between 50° C. and 56° C., and it is destroyed at 80° C.

Although the optimum temperature of ptyalin is at or near 46° C., still it acts vigorously at from 30° C. to 40° C. The conversion of starch into maltose takes place as follows : The starch grains being acted upon by hot water, take it up, and soluble starch or amyloextrin is produced. The action of ptyalin upon this is to convert it into erythroextrin and maltose ; the ptyalin, continuing its hydrolytic action, changes the erythroextrin into

achroödextrin with maltose, and the dextrin finally becomes maltose, so that in the end all the starch becomes maltose. It is considered by some authorities that what is called erythroöextrin consists in reality of several dextrans, and this is undoubtedly true of achroödextrin, of which maltodextrin may be regarded as a variety. Neumeister gives the following scheme as representing the changes through which he believes the starch passes :



*Glycogen*, when acted upon by ptyalin, undergoes the same changes as starch, but less rapidly. *Cellulose* is not affected by it, except, possibly, in young plants, when it is very tender. Inasmuch as the external portion of the starch grains is cellulose, uncooked starch is not affected by this enzyme. This is one of the reasons why starchy substances should be cooked before being eaten. In the cooking process the starch becomes hydrated by union with water, and upon hydrated starch ptyalin acts more thoroughly.

*Effect of Reaction on the Amylolytic Action of Saliva.*—The saliva, of which ptyalin is a constituent, is an alkaline fluid, and yet, as a matter of fact, this enzyme acts at its best when the reaction is neutral. If the alkalinity is excessive, its action is inhibited. When free hydrochloric acid is present, even in so small an amount as 0.003 per cent., the amylolytic action is arrested, and if much more than this, the enzyme is destroyed.

From the experiments of Chittenden and Richards, to which we have already referred, the following conclusions are drawn by them: Saliva secreted after a period of glandular inactivity as before breakfast, manifests greater amylolytic power than the secretion obtained after eating. This increased amylolysis is due primarily to an increase in the amount of active enzyme contained in the saliva. Mixed saliva, whether collected by mechanical stimulation or collected without effort, shows a natural tendency to vary in amylolytic power throughout the twenty-four hours, and apparently independently of the taking of food. This is remarkably constant between 7 and 11 A.M. Mechanical stimulation, as chewing a tasteless substance, and alcohol, ether, gin, whiskey, etc., if taken into the mouth, all lead to the outpouring of a secretion

richer in alkaline-reacting salts and in amylolytic power than the secretion coming without stimulation. Mixed saliva resulting from stimulation with ether, alcohol, etc., contains a much larger proportion of mucin than the secretion coming without stimulation, being noticeably thick and viscid. This quality is not apparent in the saliva resulting from mechanical stimulation.

*Duration of the Amylolytic Action of Saliva.*—One of the interesting questions in regard to the amylolytic action of saliva is as to its duration. As we have already seen, a very minute percentage of free acid arrests this action. The food remains in the mouth but a short time, when, in portions, each of which is an alimentary bolus, it passes through the esophagus into the stomach, a process which is also very brief, and in the latter organ it meets with a fluid, the gastric juice.

Although the amount of hydrochloric acid in this fluid is enough to arrest the action of the enzyme if it was free, still it must not be forgotten that this is not the case. It is in combination with the proteids of the gastric juice, and later with the proteids and peptones the results of stomach digestion, so that considerable time must elapse before there is enough of the free acid present to arrest the action of the ptyalin. Just how long this is, it is impossible to say in all cases, for it will vary under different conditions. Experiments made by Cannon (p. 201) show that while the contents of the pyloric end of the stomach are strongly acid, free hydrochloric acid appearing there at the end of half an hour, at the end of two hours there is no free acid in the middle of the food in the cardiac end, so that during all this time the action of the saliva may continue.

In discussing this subject Moore says: "The diastatic action of the saliva, therefore, continues in the stomach during and after a meal until (1) the alkali of the saliva has been neutralized, (2) the proteid present in solution has been satisfied, and (3) a trace of free hydrochloric acid remains in excess."

Some excellent authorities are inclined to regard the chemical action of the saliva as subordinate to the mechanical, inasmuch as in their opinion the amount of starch converted into maltose by the ptyalin is inconsiderable. This they infer from the fact that a medium as acid as the gastric juice will inhibit the action of the enzyme, and, since the food remains in the mouth and esophagus but a short time, it follows that the conditions favorable for salivary digestion must be of brief duration. It seems to us that they ignore the facts, already stated, with reference to the necessity of free acid to stop the action of the enzyme, and to the long time before this is present in the stomach in quantity sufficient to produce its effect. It is undoubtedly true that the starch digestion of the small intestine is very important, but certainly in the two hours, approximately, that the saliva acts a considerable amount

of starch can be converted, so that to the chemical action of the saliva must be assigned a greater importance than it has hitherto held.

Much of the starch not changed to sugar is changed to dextrin, according to Cannon and Day, "and thus, since dextrin is not easily fermented, the food is saved to the organism. The especial value of this process lies in the fact that it occurs to the greatest degree in the fundus, in which region the hydrochloric acid, inhibiting the action of many of the organized ferments, does not, for some time, make its appearance.

"In the early stages of gastric digestion, if food has been properly masticated, the fundus serves chiefly for the action of the ptyalin; the pyloric portion, after a brief stage of salivary digestion, is thereafter the seat of strictly peptic changes. Later, after two hours or more, as the contents of the fundus become acid, the food in the stomach, as a whole, is subjected to the action of proteolytic fermentation."

The experiments of Cannon on the movements of the stomach, to which we shall refer in detail in considering the function of that organ, demonstrate most conclusively that in the process the conditions are most favorable for a relatively prolonged action of ptyalin on starch; the principal condition being the absence of movement in this part of the stomach, so that the food remains here in an alkaline condition for a considerable length of time. This action of the saliva for so long a time after the entrance of the food into the stomach emphasizes the importance of thorough mastication and insalivation.

*Mechanical Office of Saliva.*—While the teeth are thoroughly comminuting the food they are at the same time working saliva into the interstices which they make between the particles of the food. This process not only facilitates the chemical action of the ptyalin, but it tends also to keep the particles separated, so that when the food reaches the stomach the gastric juice may the more readily permeate it and produce its characteristic action. Saliva aids also in softening the food, thus enabling the process of deglutition or swallowing more easily to be performed. The secretion of the mucous glands of the mouth is of special importance in this act, the mucus secreted being of a *ropy* consistency and possessing great lubricating properties. Saliva is intimately connected with the sense of taste. Only soluble substances are *sapid*—that is, excite the sense of taste. Insoluble substances have no taste. It is for this reason, among others, that calomel is such an excellent cathartic for children; being insoluble, it is tasteless, and they readily swallow it. Soluble substances not already in a state of solution are dissolved by the saliva, and in this condition excite the sense of taste. When in a febrile or other state, in which the secretion of the saliva is greatly dimin-



ished, deglutition is difficult and the sense of taste is markedly deteriorated.

**Deglutition.**—This is the act of swallowing, and for purposes of description is conveniently divided into three stages: 1. From the mouth to the pharynx; 2. Through the pharynx to the esophagus; and 3. Through the esophagus to the stomach.

**First Stage.**—The tongue is an organ composed of muscles, some of which have their origin outside the tongue but end in it, known as the *extrinsic* muscles, and others which are situated wholly within the organ, and constitute its greater part; these are the *intrinsic* muscles. In the former group are the styloglossus, hyoglossus, palatoglossus, and others; and in the latter the superior lingualis and inferior lingualis, together with others which we need not name. For a detailed description of the muscles of the tongue the reader is referred to anatomical text-books. The floor of the mouth is made up of the two mylohyoid muscles, which have their origin in the mylohyoid ridge and are inserted into the hyoid bone. The digastric, stylohyoid, and geniohyoid muscles need also to be mentioned in this connection.

After the solid food has been thoroughly masticated and insalivated, it is collected by the tongue, aided by the cheeks, and formed into a small mass, the *alimentary bolus*. This is placed upon the dorsum of the tongue, which is then pressed against the roof of the mouth by the action of the styloglossi and palatoglossi muscles, thus carrying the bolus backward to the base of the tongue. There is also contraction of the anterior belly of the digastric, mylohyoid, and geniohyoid muscles, elevating and moving forward the hyoid bone and the tongue, and the pharynx and larynx are thus carried upward and under the bolus. The bolus is now at the anterior pillars of the fauces, the palatoglossi muscles covered with mucous membrane. The first stage may now be considered to end and the second begin. Up to this point the movement has been a voluntary one, absolutely under the control of the will, for it would be possible at this point in the process to eject the bolus from the mouth. It is probable, however, that under ordinary circumstances the latter part of the first stage is involuntary—*i. e.*, reflex—as, indeed, are both the second and the third stages throughout.

The nerves which are involved in the first stage are the fifth nerve, supplying the mucous membrane of the mouth and the anterior portion of the tongue; and the glossopharyngeal, which is distributed to the posterior third of that organ. These are the sensory nerves, or those which carry the afferent impulses; the motor nerves are the hypoglossal, supplying the muscles of the tongue, the mylohyoid branch of the inferior dental, the largest branch of the inferior maxillary branch of the fifth, which supplies the anterior belly of the digastric and the mylohyoid.

**Second Stage.**—In this stage the bolus is carried through the pharynx, and, simple though this may appear, it must be borne in mind that there are other openings than the esophagus which communicate with the pharynx into which the bolus might be carried; these are the posterior nares and the larynx. If carried into the former, no danger would accrue; but if into the latter, and it was not at once expelled by the violent act of coughing which it would excite, a fatal result would doubtless ensue—either immediately if the bolus so blocked the larynx that no air could enter, or after a longer period if it passed through and brought about the fatal result by setting up inflammation of the air-passages or lungs.

The approximation of the base of the tongue to the soft palate and the contraction of the anterior pillars of the fauces, the palatoglossi, the so-called constrictors of the isthmus of the fauces, shut off the pharynx from the mouth and carry the bolus backward far enough to bring it within the influence of the constrictors of the pharynx. An additional obstacle to the return of the bolus to the mouth is the elevation and carrying backward of the hyoid bone by the contraction of the posterior belly of the digastric and the stylohyoid muscles. Its entrance into the posterior nares is prevented by the elevation of the soft palate caused by the action of the levator palati, which is innervated by the facial, according to Kirkes, or the internal branch of the spinal accessory, according to Gray. The soft palate is at the same time made tense by the tensor palati, supplied by a branch from the otic or Arnold's ganglion; by the contraction of the palatopharyngei muscles, which form the posterior pillars of the fauces, and are supplied by the internal branch of the spinal accessory; and by the raising of the uvula, due to contraction of the azygos uvulæ. The contracted palatopharyngei do not come closely together, but what is lacking in their approximation is made up by the uvula. This contraction of the palatopharyngei also raises the pharynx and thus brings the bolus well within it. It will be readily seen that the changes just described not only result in shutting off any possible entrance to the posterior nares, but also form of the soft palate and the posterior pillars of the fauces, with the uvula between them, a continuous surface well lubricated with mucus, and so inclined as to direct the bolus in the direction which it should take to reach the esophagus.

The upper portion of the pharynx is in reality a part of the respiratory rather than the alimentary apparatus, as is shown by the fact that its mucous membrane is covered with ciliated epithelium, as is also the upper surface of the soft palate.

The bolus has still, however, to pass the opening into the larynx without gaining entrance thereto. This is accomplished in the following manner: As we have seen, the larynx is raised in the manner described, aided by the thyrohyoid muscle,



which acts to raise the larynx when the hyoid bone ascends, and its opening closed by the contraction of the arytenoideus and the lateral crico-arytenoidei, supplied by the inferior or recurrent laryngeal nerve, a branch of the pneumogastric.

Whether the epiglottis is folded back or remains in its usual erect position during deglutition is a matter of dispute. Those who claim that it closes the glottis give various arguments to sustain the opinion and explain how it takes place. The action of the thyrohyoid, just referred to, is regarded by one authority as causing or permitting "the folding back of the epiglottis over the upper orifice of the larynx." It is further claimed that this movement can be felt by simply passing the finger into the throat until it comes in contact with the epiglottis and then performing the act of swallowing. On the other hand, there is a case on record in which enough of the pharynx was removed in a surgical operation to permit the actual inspection of the epiglottis during the act of swallowing, and it was observed to undergo no change of position. Whatever may be the fact in this regard, there is no question that the larynx is perfectly protected against the entrance of food, even though the epiglottis does not fold back during the act of deglutition.

At the close of the first stage the pharynx is raised so as to receive the bolus, and at the same time it is enlarged. This is due to the forward movement of the larynx and the tongue, both of which as they are elevated are also carried forward; and also to the contraction of the stylopharyngei, whose action is to draw upward and outward the sides of the pharynx, thus separating them and enlarging the cavity laterally. The bolus being well within the pharynx, the muscles which raised the latter relax, and it descends, carrying with it the bolus, which is now passed along by the constrictors of the pharynx to the opening of the esophagus. The stylopharyngeus receives its nerve-supply from the glossopharyngeal, while the constrictors are supplied by the pharyngeal plexus, the inferior constrictor being supplied by the external laryngeal branch of the superior laryngeal and the recurrent laryngeal.

**Third Stage.**—In this stage the bolus passes through the esophagus into the stomach. This canal is about 23 cm. in length, and from 1.8 to 2.4 cm. in breadth. When empty its walls are in apposition, and in section it presents the appearance of a transverse slit. It has three coats: 1. An internal, composed of mucous membrane, covered with stratified epithelium, as is that of the mouth and that of the pharynx from the soft palate down. 2. A submucous coat, in which are the *esophageal glands*, compound racemose glands which open by ducts upon the surface of the membrane, and which secrete mucus. These glands are most abundant near the cardiac orifice, where they encircle the esoph-

agus. 3. A muscular coat, which is arranged in two layers, an inner (circular) and an outer (longitudinal). The fibers of the circular layer form at the cardiac orifice, where the esophagus enters the stomach, a sphincter which keeps the opening closed, especially when the stomach contains food. The muscular tissue of the upper third is principally striated, while the remainder is of the involuntary variety. The nerves of the esophagus come from the pneumogastric and the sympathetic.

The circular layer of the muscular coat is continuous with the inferior constrictor, and the contraction of the fibers of this layer follows immediately upon that of the constrictor, carrying the bolus onward in its passage to the stomach. This is a continuation of the reflex act which begins certainly in the pharynx, possibly in the mouth. The bolus stimulates the mucous membrane as it passes along, and a wave of peristalsis follows. Thus each successive portion of the muscular coat contracts behind the bolus, gradually pushing it onward. When it reaches the cardiac orifice, the sphincter relaxes and the bolus is forced into the stomach. This can sometimes be heard by applying a stethoscope over the epigastric region. The time occupied by the passage of the bolus from the beginning of swallowing to the moment it enters the stomach is about six seconds. The action of the longitudinal fibers is not understood, although some authorities think that their contraction precedes that of the circular fibers, and thus tends to dilate the esophagus and bring it forward over the bolus.

The process of deglutition has been very thoroughly studied by Falk and Kronecker, by Kronecker and Meltzer, and still more recently by Cannon and Moser. The first-named experimenters have shown that there is pressure enough produced by the rapid contraction of the muscles of the mouth to force liquid food through the esophagus independently of peristalsis, and indeed before the peristaltic wave passes along. Thus, when cold water is swallowed its presence is recognized in the epigastrium almost immediately; and it has been also noted by them that when strong acids pass through the esophagus only parts of it are corroded, and not the entire surface of the mucous membrane, as would be the case were they swallowed by peristaltic action.

The second named experimenters conclude from their experiments that liquids and semisolids are forced down the esophagus, or "squirted" down, by the rapid contraction of the mylohyoid muscles, nearly as far as the cardia (cardiac orifice), and that they remain here until the peristaltic wave reaches this point, when they are carried into the stomach, which is about six or seven seconds from the beginning of swallowing.

In these experiments only liquids and semisolids were employed, and it is manifest that what might be true of these might not be true of solids. It was to determine the actual movements of

solids, as well as of semisolids and liquids, that the experiments of Cannon and Moser were performed. Some of these were on geese, cats, dogs, and horses, and some on man.

The following is the "summary" of these later experiments, as published in the *American Journal of Physiology*:

"There is a difference in swallowing according to the animal and the food which is used.

"In fowls the rate is slow and the movement always peristaltic, without regard to consistency. A squirt-movement with liquids is manifestly impossible, as the parts forming the mouth are too hard and rigid. With this diminution of propulsive power in the mouth there is observed a greater reliance on the force of gravity. The head is raised each time after the mouth is filled, and the fluid by its own weight trickles into the esophagus, through which it is carried by peristalsis.

"In the cat the movement is always peristaltic and slightly faster than in fowls. A bolus takes from nine to twelve seconds in reaching the stomach. Liquids move somewhat more rapidly than semisolids in the upper esophagus. In the lower or diaphragmatic part the rate is very much slower than above, and is the same for liquids as for solids.

"In the dog the total time for the descent of the bolus is from four to five seconds. The food is always propelled rapidly in the upper esophagus and moves more slowly below. This rapid movement is frequently continued further with liquid food. No distinct pause was observed when the movement of the bolus changed from the rapid to the slower rate.

"In man and the horse liquids are propelled deep into the esophagus at a rate of several feet a second by the rapid contraction of the mylohyoid muscles. Solids and semisolids are slowly carried through the entire esophagus by peristalsis alone."

The peristalsis of the esophagus is brought about by afferent impulses which reach the center of deglutition and from which efferent impulses pass out to the muscular coat. While the act is, therefore, principally under the control of the nervous system, the stimulation of the successive portions of the mucous membrane as the food passes along may have some part in its production.

## STOMACH DIGESTION.

The food having reached the stomach, now undergoes stomach or gastric digestion.

The stomach is a hollow organ into which the esophagus opens,

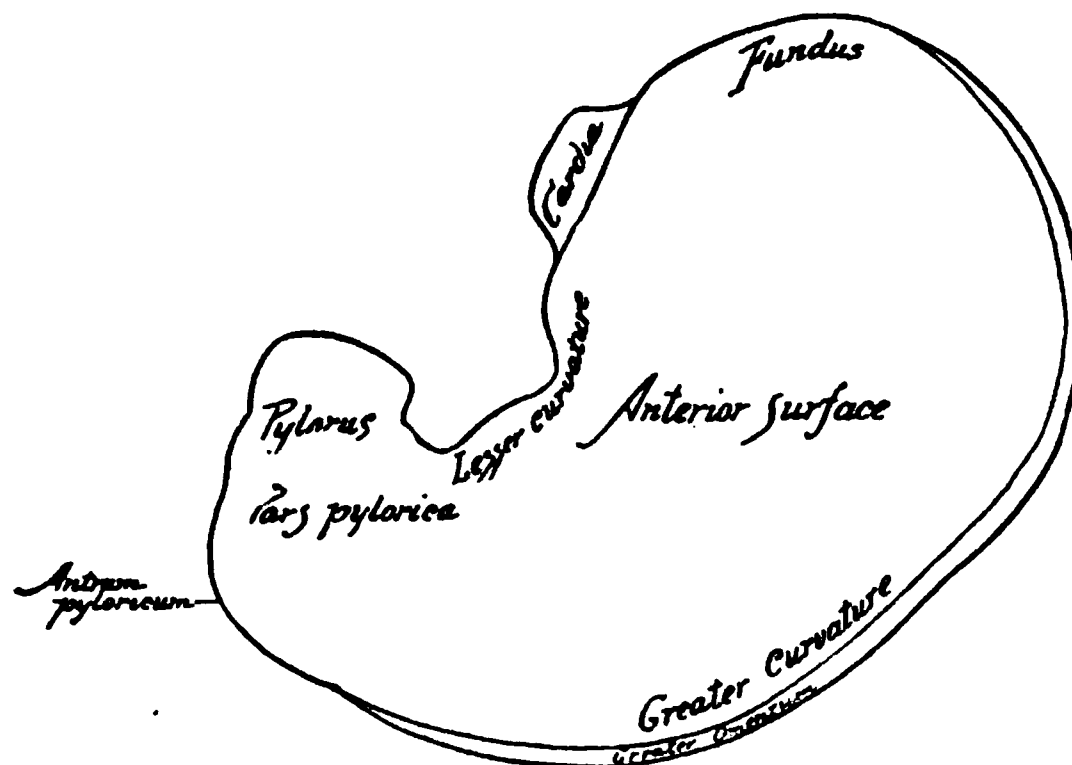


FIG. 104.—Anterior outlines of stomach. His' model.

the opening being called the *cardia* or *cardiac orifice*, and which at its lower end communicates with the small intestine through the *pyloric orifice*. Its greatest diameter is from 24 to 26 cm., and that from the lesser to the greater curvature, 10 to 12 cm. It can hold from 2.5 to 4 liters. When empty its walls are in apposition. Its form and position are shown in Figs. 104 and 105.

The study of the movements of the stomach by Cannon by means

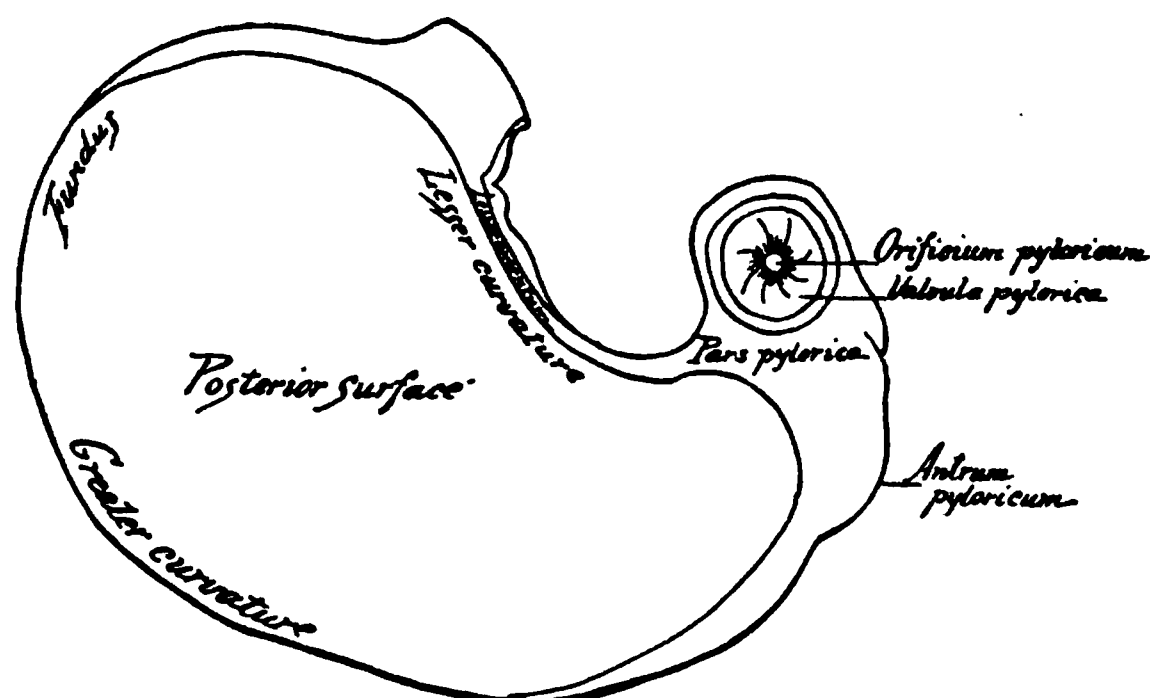


FIG. 105.—Posterior outlines of stomach. His' model.

of the Röntgen ray, using subnitrate of bismuth to throw a dark shadow on the fluorescent screen (p. 201), has brought out some

facts in regard to the anatomy of the stomach which make it desirable to reproduce here the outline of that organ as demonstrated by

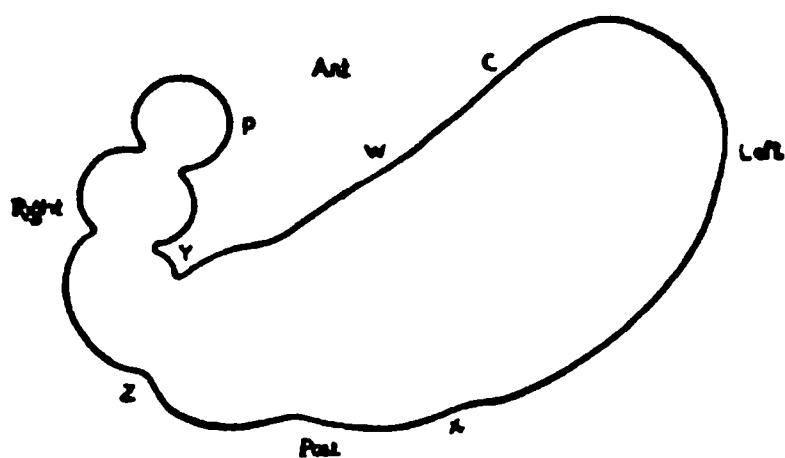


FIG. 106.—The cardiac portion is all that part to the left, as the stomach lies in the body, of *WX*. The cardia is at *C*. The pylorus is at *P*, and the pyloric portion is the part between *P* and *WX*. This has two divisions: the antrum, between *P* and *YZ*, and the pre-antral part, between *WX* and *YZ*. The lesser curvature is on the top of the outline between *C* and *P*, and the greater curvature between the same points along the lower border (*Amer. Journ. of Physiology*).

the experiments referred to. Fig. 106 represents the stomach of the cat, but probably also represents in all important particulars the human stomach as well.

### Coats of the Stomach.

—The stomach is composed of four coats: Serous, muscular, submucous, and mucous. The **serous** coat is a reflection of the peritoneum. The **submucous** coat, which contains the nerves and blood-vessels, is of special interest as giving to the mucous coat great mobility and as permitting it to form folds,

called *rugæ*, when the cavity is empty. This structure is in striking contrast with the anatomic structure of the uterus, in which organ, the submucous coat being absent and the mucous lying directly upon the muscular coat, there is a total want of mobility of the membrane. Aside from this fact, neither the serous nor the submucous coat has any special physiologic interest. The **muscular** coat is composed of three layers: longitudinal, circular, and oblique. The *longitudinal* layer is made up of fibers continuous with similar fibers of the esophagus, and is most external—that is, immediately beneath the peritoneum. These fibers radiate from the esophageal or cardiac orifice, and are especially abundant in the region of the greater and lesser curvatures. They extend to the intestine, where they form a layer of the muscular coat of that organ. The *circular* layer is situated internal to the longitudinal, and, as the name implies, its fibers encircle the stomach—that is, are in general at right angles to the longitudinal axis of the stomach. At the pyloric orifice of the stomach, where the duodenum begins, these circular fibers are aggregated in such number as to receive the name of *pyloric muscle* or *sphincter pyloricus*. Their projection into the interior of the organ at this location with its covering of mucous membrane constitutes the pyloric valve. The *oblique* layer is found especially at the cardiac extremity of the stomach.

The **mucous coat**, or **mucous membrane**, is soft and velvety. Near the cardiac orifice the membrane is about  $1\frac{1}{2}$  mm. in thickness, and near the pylorus 2 mm., while in general between these two points its thickness is about 1 mm. Its surface is composed

of columnar epithelium, which secretes the mucus found in the stomach in the intervals of digestion, this mucus being a constituent of the gastric juice.

In the mucous membrane, and forming a part of it, are two sets of glands, the *pyloric* glands, so called from their abundance in the pyloric portion of the stomach, and the *cardiac* glands (Fig. 107), which are so called because of their occurrence in the cardiac region. The pyloric glands were formerly called mucous glands, but their product is not mucus; the cells are of the serous type described in connection with the salivary glands. The ducts of both cardiac and pyloric glands are lined by columnar epithe-



FIG. 107.—Cardiac glands. Diagram showing the relation of the ultimate twigs of the blood-vessels (*V* and *A*), and of the absorbent radicals (*L*) to the glands of the stomach, and the different kinds of epithelium—namely, above, cylindrical cells; small pale cells in the lumen; outside which are the dark ovoid cells.

lium continuous with that covering the mucous membrane. In the tubes of the pyloric glands are granular cells called *chief* or *central* cells. The same kind of cells are found in the tubes of the cardiac glands; and beneath these cells—that is, between them and the basement-membrane—are, besides, large cells, which are ovoid in shape, the *parietal* or *oxyntic* cells. These cells cause the basement-membrane against which they lie to bulge out. The chief cells are regarded as producing the pepsinogen which is converted into the pepsin of the gastric juice, and the parietal cells as producing the hydrochloric acid, although the latter has not been certainly demonstrated. The vascularity of the stomach is very great. In the intervals of digestion the mucous membrane is of a

pale pinkish color, while during active digestion its color is a bright red. This change in color is due to the greatly increased amount of blood present in the blood-vessels of the organ at this time.

The pyloric portion is specially distinguished by the name *antrum pylori*, and is that part situated between the pyloric orifice and a band of circular fibers, the *transverse band* or *sphincter antri pylorici*, distant from the orifice about 10 cm. In modern physiology this portion of the stomach is invested with much interest, and is referred to on p. 201.

FIG. 108.—Left breast and side (erect position), showing perforation of the walls of the stomach of Alexis St. Martin.

under whose care the patient came, says: "The wound was received just under the left breast, and was supposed at the time to be mortal. A large portion of the side was blown off, the ribs fractured, and openings made into the cavities of the chest and abdomen, through which protruded portions of the lungs and stomach, much lacerated and burnt. . . . The diaphragm was lacerated and a perforation made directly into the cavity of the stomach, through which food was escaping at the time your memorialist was called to his relief."

When the wound healed there remained in his side a permanent opening nearly  $2\frac{1}{2}$  cm. in diameter, which communicated with the cavity of the stomach (Fig. 108). Dr. Beaumont, and subsequently others, carried on a series of experiments and observations extending through years, and the present knowledge of stomach digestion is largely based upon this remarkable case.

After the healing of his wound his health was excellent, and he lived to be eighty-three years of age.

During the intervals of digestion the mucous membrane of the stomach is pale in color, and is covered with a transparent and viscid mucus which is neutral or alkaline in reaction. This mucus is the product of the epithelium of the mucous membrane. After food has entered the stomach drops of gastric juice appear at the mouths of the glands.

**Quantity of Gastric Juice.**—The amount of gastric juice



daily secreted is difficult of determination, and it is not surprising that authorities should differ so much on this point. Dr. Beaumont estimated it to be 180 grams in the case of St. Martin, while others place it as high as 7 liters, or one-tenth of the weight of the body. The gastric juice is never in large quantity in the stomach at any one time. It is secreted gradually by the glands, is poured out into the cavity of the stomach, where it permeates the food, is passed on into the small intestine, where it is absorbed by the blood-vessels, and is then returned to the circulation, from which its constituents were derived. It has the following properties: it is clear, nearly colorless, and strongly acid. Its specific gravity is about 1002.

**Composition of Human Gastric Juice Mixed with Saliva.**—As can readily be understood, it is impossible to obtain gastric juice unmixed with particles of food or saliva or other foreign substances, hence an accurate analysis cannot be given. The analysis by Schmidt of gastric juice from a woman having a gastric fistula, which is the only complete analysis on record, is as follows:

Water . . . . .	99.4400
Organic substances (pepsin, peptones, and rennin) . . .	.3195
Free hydrochloric acid . . . . .	.0200
Calcium chlorid . . . . .	.0061
Sodium " . . . . .	.1484
Potassium " . . . . .	.0550
Calcium } phosphates . . . . .	.0125
Magnesium }	
Ferrum }	
Loss . . . . .	.0005
	<hr/> 100.0000

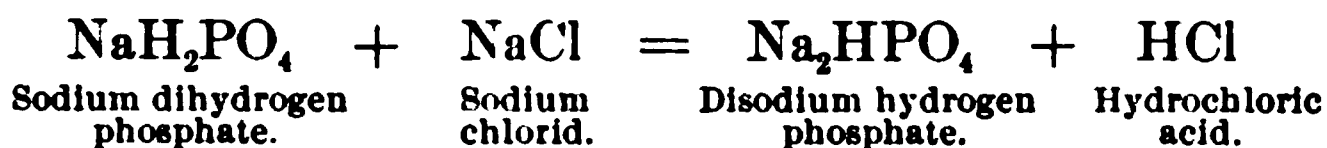
The constituents of the gastric juice of special physiologic interest are hydrochloric acid, pepsin, and rennin. It was at one time a matter of dispute whether the acidity of this fluid was due to hydrochloric or to lactic acid, but there is now a unanimity of opinion that it is the former. If lactic acid is present, it is probably due to lactic fermentation which has taken place in the carbohydrates of the food when these are in excess. This fermentation may go on to the formation of acetic and butyric acids, these changes being doubtless due to the presence of micro-organisms.

**Hydrochloric Acid.**—The amount of free hydrochloric acid in human gastric juice varies from 0.05 to 0.3 per cent. Several of the best authorities give the average as between 0.2 and 0.3 per cent.

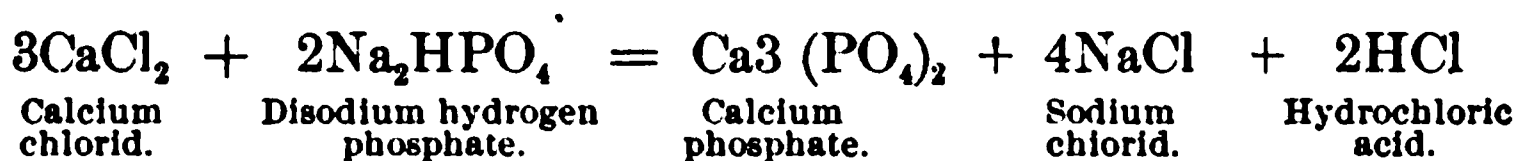
Although the only possible source of hydrochloric acid is the chlorids of the blood, which decomposing yield chlorin, and this uniting with hydrogen forms the acid, yet the manner of its for-



mation is still undecided, and various theories have been propounded to explain it. Among these, Maly's is, perhaps, the one most generally accepted. This theory is that there occurs a reaction between the phosphates and chlorids of the blood which results in the formation of hydrochloric acid. This reaction is expressed by the following equation :



Or the hydrochloric acid may be produced by the reaction between calcium chlorid and disodium hydrogen phosphate, as follows :



This theory regards the formation of the hydrochloric acid as taking place in the blood ; and being highly diffusible, it diffuses through the gastric glands into the stomach. In this explanation the cells have no part in the formation of the acid. Gamgee regards the cells of the glands, those known as parietal or oxyntic, as the acid producers, and supposes that they have a peculiar power of selecting the alkaline phosphates and the chlorids from the other constituents of the blood, and that the reaction already referred to takes place in them, hydrochloric acid resulting. But, as we have already said, this is pure theory, and has never been demonstrated. About all that can be said is that the hydrochloric acid is probably produced by the parietal cells from the chlorids of the blood, and that is their special function, as is that of the chief cells to produce pepsinogen or the cells of the salivary glands to produce ptyalin.

Besides the action of hydrochloric acid in connection with digestion, it has still another which is under some circumstances one of great importance—that is, its action on pathogenic bacteria ; we shall discuss the subject of Bacterial Digestion later (p. 253), but here we desire to call attention to the protective influence which the hydrochloric acid of the gastric juice exerts against certain well-known diseases.

The preservative power of gastric juice on meat, due to the action of the hydrochloric acid on putrefactive bacteria, has long been known. The cholera spirillum, the germ which produces Asiatic cholera, will not survive in fluid of the acidity of the gastric juice of the guinea-pig and the rabbit. Nor has cholera been produced when, after first neutralizing the gastric juice by administering soda, cholera cultures have been ingested. But if opium is given with the soda, and intestinal peristalsis slowed

down thereby, choleraic symptoms result. Koch produced genuine cholera in animals by opening the abdomen, tying the bile-duct, and then injecting cholera cultures directly into the intestines. It would appear from the evidence taken as a whole that, if the stomach is in a normal condition, cholera germs will be destroyed by the gastric juice. It is not improbable that if the stomach is the seat of catarrhal inflammation, as might be caused by alcohol taken for a long time in excess, the conditions in the stomach-cavity would be favorable to the reception and growth of the cholera spirilla, and the disease be produced. Falk claims that the bacillus of anthrax is destroyed by gastric juice, except when in the sporulating stage, but that this fluid has no effect on the tubercle bacillus.

Writing on this general subject, Sternberg, in his *Manual of Bacteriology*, says: "The experiments of Straus and Würtz and of others show that normal gastric juice possesses decided germicidal power, which is due to the hydrochloric acid contained in it. Hamburger (1890) found that gastric juice containing free acid is almost always free from living micro-organisms, and that it quickly kills the cholera spirillum and the typhoid bacillus, but has no effect upon anthrax spores. Straus and Würtz found that the cholera spirillum is killed by two hours' exposure in gastric juice obtained from dogs, the typhoid bacillus in two or three hours, the anthrax bacillus in fifteen to twenty minutes, and the tubercle bacillus in from eighteen to thirty-six hours. The experiments of Kurlow and Wagner, made with gastric juice obtained from healthy men by means of a stomach-sound, gave the following results: Anthrax bacilli without spores failed to grow after exposure to the action of human gastric juice for half an hour, but spores were not destroyed in twenty-four hours; the typhoid bacillus was killed in one hour; the cholera spirillum, the bacillus of glanders, and *Bacillus pyocyaneus* were all destroyed at the end of half an hour; the pus cocci showed great resisting-power. Certain bacteria have a greater resisting-power for acids than any of those above mentioned, and some of them may consequently pass through the healthy stomach to the intestine in a living condition, but there is good reason to believe that the spirillum of cholera or the bacillus of anthrax would not. On the other hand, the tubercle bacillus and the spores of other bacilli can, no doubt, pass through the stomach to the intestine without losing their vitality."

The hydrochloric acid of the gastric juice when free certainly destroys many non-pathogenic bacteria introduced with the food, which otherwise might cause it to decompose; thus both lactic and acetic fermentations are prevented; it is said, however, that hydrochloric acid when combined with proteids does not have this power. Cohn explains the action of the free acid by supposing

that it decomposes the alkaline phosphates, without which the bacteria cannot live.

**Pepsin**—The chief or central cells of the cardiac glands present a granular appearance ; this is due to granules which are the product of the cells, and consist of a zymogen, *pepsinogen*. During gastric digestion they diminish, so that the outer portions of the cells become quite clear, losing the granular appearance, while the inner portions, or those near the lumen of the tube, retain it. While the chief cells of the cardiac glands doubtless produce most of the pepsinogen, still it has been abundantly proved that the same variety of cells of the pyloric glands also produces this zymogen. The pepsinogen thus formed becomes converted into pepsin, which exists in the human stomach at birth.

Pepsin is a proteolytic enzyme which acts only in an acid medium, so that the presence of the acid is as essential to stomach-digestion as is that of the enzyme. While hydrochloric acid gives the best results, some other acids may be substituted ; thus nitric and lactic, and even oxalic and tartaric acids, will exert a proteolytic action.

In the case of pepsin, as also of ptyalin, and indeed of all enzymes, the effect of temperature upon the zymolytic process must always be considered. The optimum temperature for the action of pepsin is from 37° to 40° C. ; while if exposed to 80° C. in a moist state, the enzyme loses its proteolytic power. Low temperatures inhibit its action, but it still acts, though feebly, at 0° C.

It has already been stated that the enzymes have not as yet been obtained in sufficient quantity or sufficiently separated from other substances to analyze, so that the composition of pepsin is still undetermined.

**Pepsin-hydrochloric Acid**.—It is held by some authorities that the pepsin and the hydrochloric acid exist in gastric juice in a state of combination, to which the name of pepsin-hydrochloric acid has been given, but this cannot be said to have been demonstrated.

**Rennin**.—This enzyme exists in human gastric juice at birth, and it appears to be more abundantly produced in the fundus than in the pyloric region, though the exact seat of its formation is not determined. Its action is to coagulate the caseinogen ; the changes which this undergoes in the process of coagulation have already been fully discussed (p. 112), and need not be repeated here. Its optimum temperature is between 38° and 40° C., while at 63° C. in an acid medium it is destroyed. The curdling process precedes the action of the hydrochloric acid and pepsin during the gastric digestion of milk.

Mothers are sometimes alarmed when their children, seemingly in perfect health, vomit curdled milk ; but, as has been stated, this

curdling is a physiologic process, and the only abnormality is its regurgitation, which is usually due to overfeeding.

**Action of the Gastric Juice.**—Having considered the composition of the gastric juice, we are now in a position to discuss its action upon the food.

**Action on Proteids.**—When proteids reach the stomach by the process of deglutition they meet with the gastric juice, whose hydrochloric acid converts them into acid-albumins. Some writers use the term syntonin as synonymous with acid-albumins; others restrict its use to the special acid-albumin which results from the action of the acid upon myosin. This change in the proteids is more quickly and completely brought about by the acid when pepsin is present than when the acid acts by itself. The acid-albumin (syntonin) takes up water, and undergoes a “cleavage” or splitting up, as a result of which two soluble proteids are formed, *proto-proteose* and *hetero-proteose*, which are together known as *primary proteoses*. This is due to the action of the pepsin, which is, therefore, a proteolytic enzyme. The process, however, does not cease here; the action of the pepsin continuing, the primary proteoses take up water and in turn split, forming *secondary* or *deutero-proteoses*. These in turn undergo hydrolytic cleavage, forming as final products, peptones. Inasmuch as there are doubtless two varieties of peptones, as will be seen in the discussion of the digestion of proteids by the pancreatic juice, these are called *ampho-peptones*. For the distinguishing characteristics of peptones and proteoses the reader is referred to p. 106.

**Action on Carbohydrates.**—Cane-sugar is undoubtedly inverted in the stomach to dextrose and levulose, the hydrochloric acid being the agent in the inversion. All the cane-sugar of the food, however, does not undergo this change in the stomach, some of it not being inverted until it reaches the small intestine.

There is some evidence looking toward the presence in the gastric juice of an amylolytic enzyme, but this is as yet too incomplete to require more than mention.

The changes which starch undergoes during stomach digestion are elsewhere described.

**Action on Fats.**—The temperature of the stomach, 38° C., renders the fats more fluid. If the fat is in the form of adipose tissue—that is, enclosed in adipose vesicles—the walls of the latter being proteid in character undergo proteid digestion, setting the fat free; but the latter is not emulsified. The evidence that fat is split up and fatty acids liberated in the stomach is accumulating; it is believed that this is due to a lipolytic enzyme, whose action is inhibited by hydrochloric acid and pepsin.

**Action on Albuminoids.**—Of all the albuminoids which enter into the food, gelatin is the most important. It is found in

various jellies and in soups. When acted upon by hydrochloric acid and pepsin it becomes converted into *gelatoses*. In the stomach these undergo no further change, but in the intestine *gelatoses* become *gelatin peptones* under the influence of the trypsin of the pancreatic juice.

**Movements of the Stomach.**—These were observed very carefully by Dr. Beaumont in the case of St. Martin (p. 194), and in order that we may the better refer to the results of recent investigations we will here quote his description. He says: "The bolus, as it enters the cardia, turns to the left, passes the aperture, descends into the splenic extremity, and follows the great curvature toward the pyloric end. It then returns in the course of the small curvature, makes its appearance again at the aperture, in its descent into the great curvature, to perform similar revolutions." This occupied in St. Martin's case from one to three minutes.

Before describing the results of Cannon's experiments as recorded in the *American Journal of Physiology*, and which were performed upon cats, we will first describe the movements of the human stomach, as they are usually described.

Before food enters the stomach, this organ being empty, its walls are in apposition and its mucous membrane arranged in rugæ. The first portions of food that enter separate the walls, but in all portions except where the food is they are still in contact. The presence of food stimulates the muscular coat, and as a result the circular fibers begin to contract feebly and on the side of the great curvature, setting up a wave of peristalsis which travels on toward the pylorus, becoming stronger as it progresses. Just before it reaches the antrum it appears to be stopped by the "pre-antral" constriction, which is the name given by Hofmeister and Schütz, to whom we owe these observations, to a constriction of circular fibers which surrounds the whole stomach in this region. This has the effect of pushing some of the stomach-contents into the antrum; the sphincter antri pylorici now contracts, and the antrum is practically shut off from the fundus. The muscular coat of the antrum then contracts, and its contents are forced against the pylorus. The pyloric muscle relaxes to permit liquid material to pass through into the duodenum; if, however, solid particles come against it, the relaxation does not occur, but an antiperistaltic wave is set up in the musculature of the antrum which carries the materials back into the fundus, the separation of the latter from the antrum having ceased owing to the relaxation of the sphincter antri pylorici. The contents are thus retained in the stomach to be further acted upon by the gastric juice until they are rendered sufficiently liquid to pass the pylorus. During these muscular movements the food is not only carried

toward the pylorus, but it is also thoroughly mixed with the gastric juice, and thus the action of the latter is more complete and efficient than it otherwise would be.

**Experiments of Cannon.**—We deem a somewhat detailed account of these experiments warranted, for the reason that, although they were made upon the cat, the evidence is conclusive that the character of the movements of the human stomach during digestion differs in no essential particular from that of the movements of the stomach of the animal which was the subject of experimentation.

Cannon and Day state that "observations with the *x*-rays have proved that the stomach of the cat is like that of the dog, rat, rabbit, guinea-pig, and man, in being separable into two parts: the quiet cardiac end and the active pyloric end. Moreover, the mucosa of the cat's stomach resembles that of the dog and of man, not only in structure but also in pouring out an active secretion from almost every part of its surface."

*Movements of the Pyloric Part.*—Within five minutes after a cat has finished a meal of bread mixed with subnitrate of bismuth there is visible near the duodenal end of the antrum a slight annular contraction which moves peristaltically to the pylorus; this is followed by several waves recurring at regular intervals. Two or three minutes after the first movement is seen, very slight constrictions appear near the middle of the stomach, and, pressing more deeply into the greater curvature, course slowly toward the pyloric end. As new regions enter into constriction the fibers just previously contracted become relaxed, so that there is a true moving wave, with a trough between two crests. When a wave swings round the bend in the pyloric part the indentation made by it deepens, and as digestion goes on the antrum elongates and the constrictions running over it grow stronger, but, until the stomach is nearly empty, do not divide the cavity. After the antrum has lengthened, a wave takes about thirty-six seconds to move from the middle of the stomach to the pylorus. At all periods of digestion the waves recur at intervals of almost exactly ten seconds. It results from this rhythm that when one wave is just beginning several others are already running in order before it. Between the rings of constriction the stomach is bulged out (Figs. 109–111). In one experiment the cat was fed 15 grams of bread at 10.25 A.M. The waves were running regularly at 11 o'clock. The stomach was not free from food until 6.12 P.M. At the rate of 360 waves per hour, approximately 2600 waves passed over the antrum during the single digestive period.

*Movements of the Pyloric Sphincter.*—Ten or fifteen minutes elapse after the first constriction of the antrum before food appears



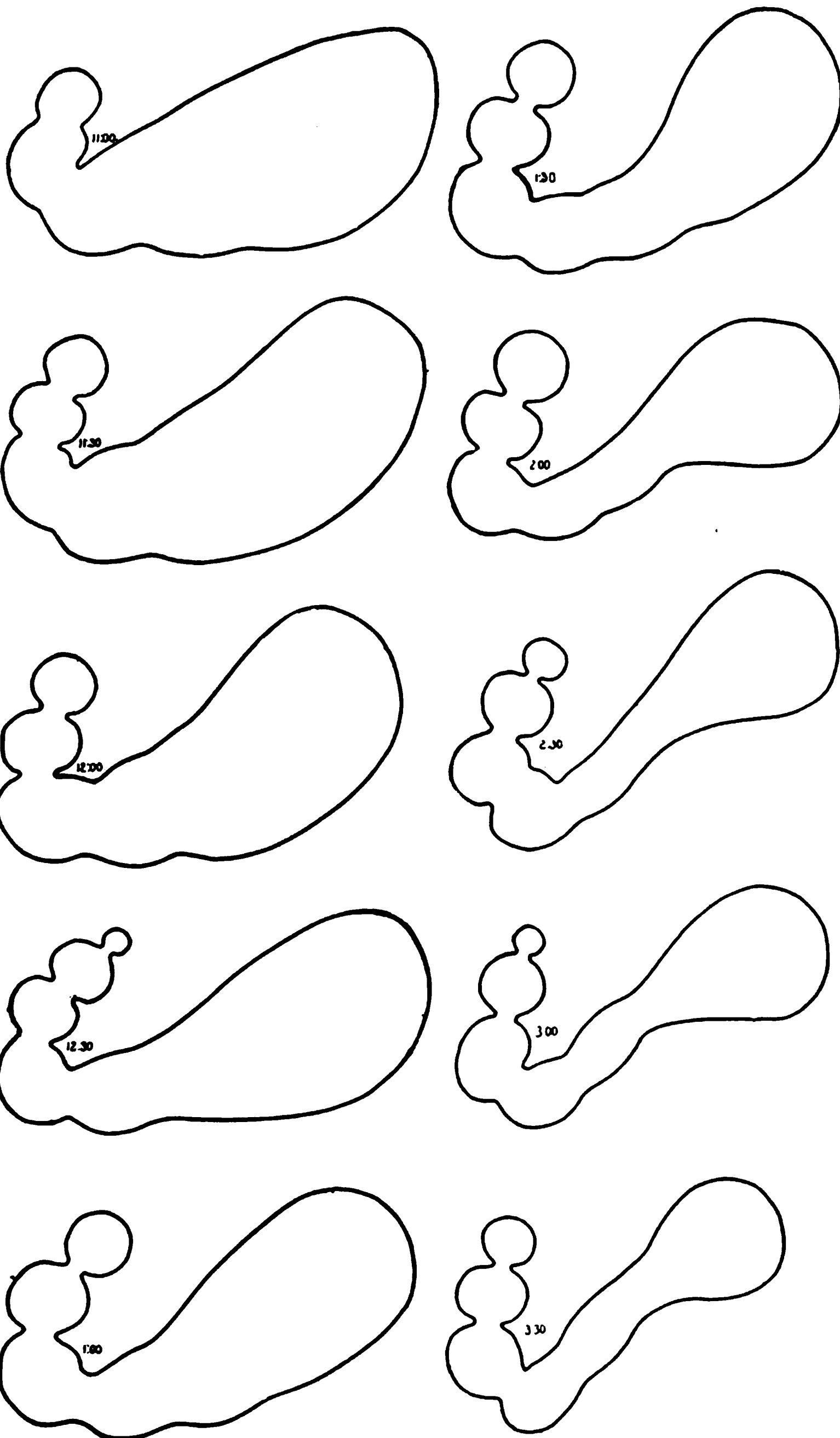


FIG. 109.

FIG. 110.

(Cannon, in *American Journal of Physiology*.)

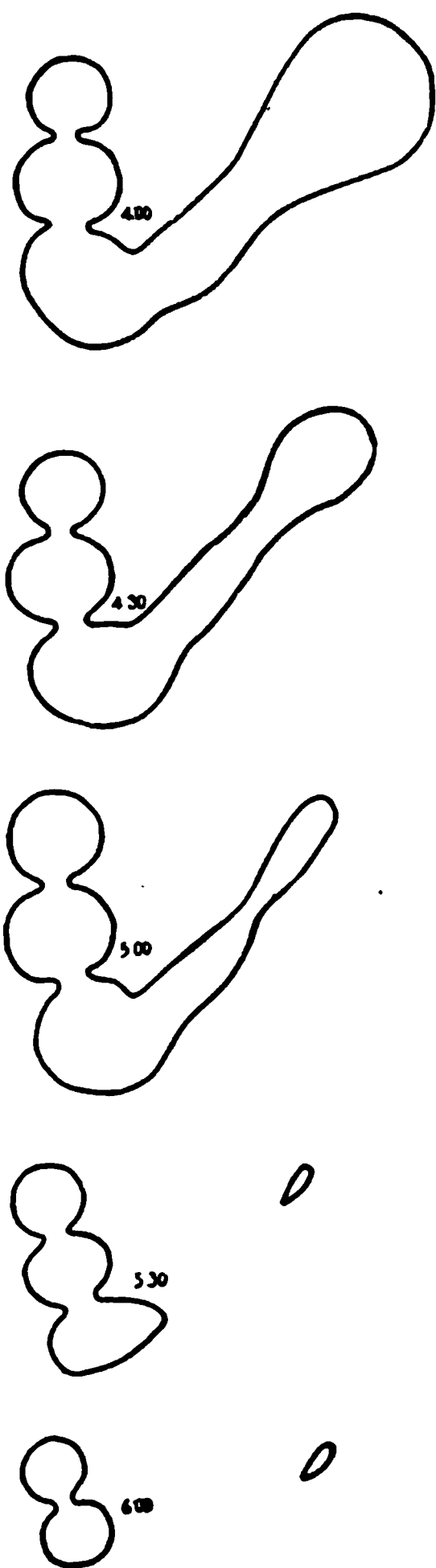


FIG. 111.—Figs. 109, 110, and 111 present outlines of the shadow of the contents of the stomach cast on a fluorescent screen by the Röntgen rays. The drawings were made by tracing the outline of the shadow on tissue-paper laid upon the fluorescent surface, and are about one-half the actual size. They show the change in the appearance of the stomach at intervals of half an hour from the time of eating until the stomach is nearly empty (*Am. Jour. of Physiology*).

and that the constrictions make deeper indentations in it; but

in the duodenum. This is spurted through the pylorus and shoots along the intestine for two or three centimeters. Not every constriction-wave forces food from the antrum. In one of the experiments which were conducted by Cannon, about an hour after the movements began, three consecutive waves squirted food into the duodenum. The pylorus remained closed against the next eight waves, opened for the ninth, but closed again for the tenth and eleventh. In this irregular manner the food passed from the stomach. Cannon expresses the opinion that near the end of gastric digestion, when the constrictions are very deep, the pylorus may open for every wave. When a hard bit of food reaches the pylorus, the sphincter closes tightly and remains closed longer than when the food is soft. On one occasion, during these experiments, when a hard particle of food reached the pylorus, the sphincter opened only seven times in twenty minutes. It is inferred from these results that hard morsels keep the pylorus closed and hinder the passage of the food into the duodenum.

*Activity of the Cardiac Portion.*—The part played by the cardiac portion has not hitherto been properly appreciated. It has been regarded as the place for peptic digestion or as a passive reservoir for food; but it is in fact a most interestingly active reservoir. Figs. 109–111 represent the appearances the stomach presents at various stages in a digestive period. A comparison of them shows that as digestion proceeds the antrum appears gradually to elongate and acquire a greater capacity, and that the constrictions make deeper indentations in it; but



when the fundus has lost most of its contents the longitudinal fibers of the antrum contract to make it shorter and smaller.

The first region to decrease markedly is the pre-antral part of the pyloric portion. The peristaltic undulations, caused by the circular fibers, start at the beginning of this portion and gradually, by their rhythmic recurrence, push some of the contents into the antrum. As the process continues the smooth muscle-fibers with their remarkable tonicity contract closely about the food that remains, so that the middle region comes to have the shape of a tube (Figs. 110, 111, 1.30 P.M. to 5.30 P.M.), with the rounded fundus at one end and the active antrum at the other. Along the tube very shallow constrictions may be seen following one another to the pylorus.

At this juncture the longitudinal fibers which cover the fundus like radiating fingers, and the circular and oblique fibers reaching in all directions about this spherical region, begin to contract. Thus the contents of the fundus are squeezed into the tubular portion. This process, accompanied by a slight shortening of the tube, goes on until the shadow cast by the fundus is almost obliterated (Fig. 111, 5.30 P.M.). This shows that the fundus is nearly empty, for there being but little subnitrate of bismuth in it, only a small shadow is cast.

The waves of constriction moving along the tubular portion force the food onward as fast as they receive it from the contracting fundus, and when the fundus is at last emptied they sweep the contents of the tube into the antrum (Fig. 111, 5 P.M. to 6 P.M.). Here the operation is continued by the deeper constrictions, till finally (in this instance, at 6.12 P.M.), with the exception of a slight trace of food in the fundus, nothing at all is to be seen in the stomach.

The food in the fundus may possibly be slightly affected by the to-and-fro movements of the diaphragm in respiration. With normal breathing the upper border of the cardiac portion swings through about one centimeter; with dyspnea, or deep breathing, through one and a half or two centimeters. Since the lower border does not move so much, the contents are gently pressed, and then released from pressure, at each respiration.

Cannon calls attention to the observation made by Moritz with reference to the value of an organ like the stomach for holding the bulk of the food, and serving it out little at a time so that the intestines may not become congested during their digestive and absorptive processes, and says that all of the advantages supposed to be thus secured to the intestines may be claimed for the stomach itself.

The experiments above quoted prove that the stomach is composed of two physiologically distinct portions. The busy antrum, over which during digestion constriction-waves are running in

continuous rhythm ; and the cardiac part, which is an active reservoir, pressing out its contents a little at a time as the antral mechanism is ready to receive them.

*Effect of the Movements of the Stomach upon the Food.*—The experiments of Cannon demonstrate, in the cat at least, that the idea of Beaumont that there is what may be called a circulation of food from the cardia along the greater curvature to the pylorus, and back along the lesser curvature, and that of Brinton that there are peripheral currents from the cardia along the walls of the stomach to the pylorus, and that these currents then unite and come back to the cardia as an axial current, are incorrect. What has been actually observed by Cannon shows conclusively that as the constriction-waves approach a given portion of food, this latter is pushed forward in the direction of the pylorus, but not moving as fast as the wave, the constriction overtakes it, and as it passes it pushes the food backward, for in this direction is the least resistance ; the next wave pushes it forward a little further than the preceding one, and as it passes again it is pushed backward, but all the time it is making headway, though slowly, for the progress exceeds the backward movement. This to-and-fro movement is more marked in the antrum, where the waves are deep, than in the middle region.

On different occasions the portions of the food under observation have occupied from nine to twelve minutes in passing from where the waves first affected them to the pylorus—*i. e.*, on the way they were moved back and forth by more than fifty constrictions.

When the pylorus is closed, the food being pushed forward by the advancing constrictions, which are here very deep, and not being able to escape into the duodenum, is squirted back through the constricted ring. This process is repeated again and again until the sphincter relaxes and the fluid parts pass out, or if not rendered liquid pass into the duodenum later in a solid condition. The solid portions then remain in the antrum, to be here acted upon by the gastric juice, and to be subjected to the tireless rubbing of the muscular coat.

In the above *résumé* we have used the language of the experimenter in describing his observations, condensing it where possible, but endeavoring not to alter his interpretation of the experiments.

The researches of Pawlow lead to the conclusion that the relaxation of the sphincter pylori is due to the contact of free hydrochloric acid, and not to any mechanical action of the food.

**Vomiting.**—The act of vomiting consists in an expulsion of the contents of the stomach through the esophagus and the mouth. Before the expulsive act takes place there are commonly nausea and an increased secretion of saliva. Then a deep inspiration occurs, caused by the descent of the diaphragm ; the glottis is closed by the contraction of the arytenoid and the lateral crico-

arytenoid muscles ; and the posterior nares are closed by the contraction of the palatopharyngei muscles or the posterior pillars of the fauces. The cardiac sphincter becoming relaxed, the cardia opens ; while the pyloric sphincter being contracted, the pyloric orifice is closed. The abdominal muscles now contract, and the diaphragm forming a non-yielding wall above the stomach, this organ is so compressed that its contents are forced into the esophagus with sufficient power to carry them through the mouth to the exterior. Under some circumstances this force is sufficient to eject them into the posterior nares and out through the nose.

Although the abdominal muscles are the principal factors in producing the expulsive movements, and indeed are in themselves sufficient, as was demonstrated by Magendie when he removed the stomach and substituted for it a bladder containing water, still there is also a contributing factor in the antiperistaltic contraction of the muscular coat of the stomach. Under some circumstances there is also an antiperistaltic wave in the muscular coat of the small intestine, by which its contents are forced into the stomach and then vomited. Whether this antiperistaltic action occurs or not in the muscular coat of the esophagus is a matter which is still unsettled.

The above description, which fairly represents the modern views as to the act of vomiting, is modified by the investigations of Openchonski on dogs and rabbits, and still more recently by Cannon on cats. The former's description is as follows : " As the result of an emetic there occurs a quickening of the walls of the stomach near the pylorus, which appears later in the antral and middle regions of the stomach. This becomes a contraction most marked in the antrum. The fundus enlarges in a spherical form, and into it the contents of the stomach are forced by these contractions of the antrum ; then follow the contractions of the abdominal muscles which force the contents into the esophagus."

Cannon made his observations upon a cat, to which he gave apomorphin as an emetic. The upper circular muscles relax and become so flaccid that the slightest movement of the abdomen changes the form of the fundus. Then there are apparently irregular twitchings of the fundus wall. Soon a deep constriction starts about three centimeters below the cardia, and, growing in strength, moves toward the pylorus. When it reaches the transverse band the constriction tightens and holds fast, while a wave of contraction sweeps over the antrum. Another similar constriction follows. In the interval the transverse band relaxes slightly, but tightens again when the second wave reaches it. Perhaps a dozen such waves pass ; then a firm contraction at the beginning of the antrum completely divides the gastric cavity into two parts. This same division of the stomach into two parts at the transverse band is to be seen when mustard is given. Now, although the waves are still running over the antrum, the whole pre-antral

part of the stomach is fully relaxed. A flattening of the diaphragm and a quick jerk of the abdominal muscles, accompanied by the opening of the cardia, next force the contents of the fundus into the esophagus. As the spasmodic contractions of the abdominal muscles are repeated, the gastric wall again tightens around the contained food. Cannon has seen antiperistalsis but once, when a constriction started at the pylorus and ran back, over the antrum, completely obliterating the antral cavity.

In the discussion of the movements of the stomach we have quoted largely from the paper of Cannon, and desire here to express our admiration of what we regard as one of the most valuable contributions to the physiology of the stomach since the time of Dr. Beaumont, and in concluding this part of the subject we quote the following statement and summary. He says:

"Although my observations do not support their (Beaumont and Brinton) theories of mixing currents running throughout the stomach, they still show that the pyloric portion is an admirable device for bringing all of the food under the influence of the glandular secretions of that organ. For, when a constriction occurs, the secretory surface enclosed by the ring is brought close around the food lying within the ring in the axis of the stomach. As this constriction passes on, fresh areas of glandular tissue are continuously pressed in around the narrow orifice. And also, as the constriction passes on, a thin stream of gastric contents is continuously forced back through the orifice and thus past the mouths of the glands. The result of this ingenious mechanism is that every part of the secretory surface of the pyloric portion is brought near to every bit of food before the latter leaves the stomach, a half hundred times or more."

"*Summary.*—1. By mixing a harmless powder, subnitrate of bismuth, with the food, the movements of the stomach can be seen by means of the Röntgen rays.

"2. The stomach consists of two physiologically distinct parts: The pyloric part and the fundus; over the pyloric part, while food is present, constriction-waves are seen continually coursing toward the pylorus; the fundus is an active reservoir for the food, and squeezes out its contents gradually into the pyloric part.

"3. The stomach is emptied by the formation, between the fundus and the antrum, of a tube along which constrictions pass. The contents of the fundus are pressed into the tube, and the tube and antrum slowly cleared of food by the waves of constriction.

"4. The food in the pyloric part is first pushed forward by the running wave, and then, by pressure of the stomach-wall, is returned through the ring of constriction; thus the food is thoroughly mixed with gastric juice, and is forced by an oscillatory progress to the pylorus.

"5. The food in the fundus is not moved by peristalsis, and consequently is not mixed with the gastric juice; salivary digestion can therefore be carried on in this region for a considerable period without being stopped by the acid gastric juice.

"6. The pylorus does not open at the approach of every wave, but at irregular intervals. The arrival of a hard morsel causes the sphincter to open less frequently than normally, thus materially interfering with the passage of the already liquefied food.

"7. The solid food remains in the antrum to be rubbed up by the constrictions until triturated, or to be softened by the gastric juice, or later it may be forced into the intestine in the solid state.

"8. The constriction-waves have, therefore, three functions: The mixing, trituration, and the expulsion of the food.

"9. At the beginning of vomiting the gastric cavity is separated into two parts by a constriction at the entrance to the antrum; the cardiac portion is relaxed, and the spasmodic contractions of the abdominal muscles force the food through the opened cardia into the esophagus.

"10. The stomach movements are inhibited whenever the cat shows signs of anxiety, rage, or distress."

**Excretory Function of the Stomach.**—The excretion of morphin and the venom of snakes by the gastric and intestinal mucous membrane, when they have been subcutaneously injected into the body, suggests that this power of excretion may under some circumstances be an important function of the gastro-intestinal tract. Experiments with cesium and strontium have demonstrated that they are eliminated by the same channel. Iron may also be eliminated by the action of the intestinal epithelium.

**Effect of Nervous Disturbances upon Gastric Digestion.**—It is a matter of common experience that fear, worry, anger, the reception of unexpected news, either joyous or sorrowful, will oftentimes seriously interrupt gastric digestion. In the case of St. Martin, Dr. Beaumont observed that when his temper was irritated the secretion of gastric juice was greatly interfered with or even suspended. Unusual fear or a condition of fever would produce the same results. Cannon observed that when the cats that were the subjects of his experiments were angry, or when their breathing was stopped by preventing the entrance of air into the air-passages, there was a total suspension of the motor activities of the stomach together with a relaxation of the antral fibers.

**Self-digestion of the Stomach.**—One of the interesting and still unexplained physiologic enigmas is: Why does not the stomach, which is proteid in its nature, undergo self-digestion during life? It is known that when death takes place during the period of active stomach digestion, erosion of the mucous membrane, and even perforation of the wall of the stomach, may occur. As

this takes place at the most dependent portion, where the gastric juice naturally gravitates, the explanation is simple. But if this self-digestion can occur after death, why not during life? No satisfactory answer to this question has yet been given, although many theories have been advanced. One of these was, that there was in living things the "principle of life," and that so long as this principle existed it exercised a protecting influence; but the fallacy of this theory was made apparent when it was shown that the leg of a living frog, passed through a fistula in a dog's stomach, did undergo digestion. Still another theory was that the gastric juice could act only when it contained the requisite amount of hydrochloric acid, and that its acidity was neutralized by the alkaline blood, so that the stomach, so long as life existed and blood was flowing through its vessels, could not be digested. But while this might explain the non-digestion of the stomach by the gastric juice, it would not account for the non-digestion of the intestine, which is also permeated by alkaline blood, but whose digestive fluids are likewise alkaline. The presence of mucus has been regarded by some as protecting the underlying mucous membrane from the action of the gastric juice, while others have attributed the same functions to the epithelium which covers it. As a matter of fact, no explanation has as yet been given which is perfectly satisfactory.

**Duration of Stomach Digestion.**—The duration of stomach digestion is variable, and depends upon several circumstances, among which is the composition of the stomach-contents. Some kinds of food remain in the stomach longer than others. Stomach digestion may in general be said to be from one and a half to five and a half hours. The following table contains a list of some of the substances with which Dr. Beaumont experimented, and the length of time they remained in the stomach :

Kind of food.	Time.
Pigs' feet and tripe . . . . .	1 hour.
Salmon . . . . .	1 "
Milk . . . . .	2 hours.
Potato, roasted . . . . .	2 "
Roast turkey . . . . .	2½ "
Soft-boiled eggs . . . . .	2½ "
Beefsteak, broiled . . . . .	2½ "
Hard-boiled eggs . . . . .	3 "
Potatoes, boiled . . . . .	3½ "
Pork, boiled . . . . .	4½ "
" roasted . . . . .	5½ "

The above table, and others of like nature, are to be very cautiously made use of in determining the digestibility of the different foods. The observations here recorded simply indicate the length of time the respective articles remained in the stomach, and nothing more. Substances are digested when they are in condition to be absorbed, and not until then. Whenever any



portion of the food is rendered sufficiently liquid, it is liable to pass out from the stomach, although there are other factors than this liquid character of the food. If two different articles of food were in the stomach at the same time, one might pass out from that organ into the small intestine in one hour, while the other might remain in the stomach two hours. From this fact alone one would not be justified in assuming that the one substance was twice as digestible as the other, for the former might not at the time it left the stomach have been prepared for absorption, but might require several hours for such a change after it reached the small intestine; while the latter, although it remained in the stomach an hour after the former had left it, might at the time it left the stomach have been in a condition to pass at once into the blood.

The practical use of tables showing the length of time that different substances remain in the stomach seems to be to determine of what the food should consist when this organ is unable to perform its function in a normal manner, and it is considered wise to lighten its labors as much as possible. For this purpose such food should be selected as will remain in the stomach but a short time, even though it pass out in an undigested state, for, as will hereafter be seen, the peptonizing function may be carried on in the small intestine as in the stomach; and in a disabled condition of the latter organ, and even when this is absent, the former will supplement it. In the dog, so thoroughly may digestion be performed by the intestines alone, without the aid of the stomach, that this latter has been almost completely removed, yet the animal has been kept alive in excellent health and strength. The first removal of this kind was by Czerny, and the dog lived for five years. After death it was examined, and it was found that in the operation all the organ had been removed except a small portion of the cardiac extremity. The animal ate all kinds of food and thrived on them.

**Trial-meals.**—Some light has been thrown on this question of the duration of stomach digestion by the application of methods of obtaining and examining the contents of the stomach for diagnostic purposes. To ascertain how far the digestive process is interfered with, *trial-meals* are given. The stomach is evacuated by means of a soft-rubber stomach-pipe after a proper time, and inspection shows to what stage the process of digestion has advanced.

Hemmeter recommends the following plan of procedure: At 8 A.M. should be given one small piece of beef, scraped and broiled = 80 gm.; 1 soft-boiled egg; 30 gm. of boiled rice; 1 glass of milk = 250 c.c.; and a piece of bread. Four or five hours later an Ewald test-meal, consisting of a roll or a piece of wheat bread and 500 c.c. of water, or tea without milk or sugar, is given, and one hour after this the stomach-contents are drawn. In giving a test-meal, Hemmeter recommends that good chewing

should be insisted on, and all food-substances should be very finely cut up, so that they cannot plug up the tube, even if not digested. The advantages claimed for this test-meal are that after drawing it, in a large number of instances, the conditions of gastric motility and secretion may be recognized before any analysis is made; then, a disappearance of the entire breakfast-meal points to a normal digestion. "Absence of all proteids—beef and egg—and presence of considerable carbohydrates—rice and bread—point to hyperchlorhydria; and, again, absence of all carbohydrates and presence of some of the beef and egg point to hyperchlorhydria, subacidity, anacidity, or achylia. Presence of the entire meal, with perhaps milk uncurdled, means impaired motility, with atrophy of gastric mucosa, absence of acids, enzymes, and pro-enzymes. If the entire meal has disappeared, the status of the gastric secretions may be ascertained from the Ewald test-meal, which is still present."

In his discussion of the physiology of gastric peristalsis, Hemmeter concludes as follows: "It is necessary to distinguish the movements of the (1) fundus, (2) pre-antral portion, (3) antrum, and (4) pyloric sphincter. (1) The motor apparatus of the stomach is represented by its muscular fibers. When these are most developed, the peristalsis is strongest; when they are least developed, it is weakest. (2) The fundus has a thin muscular development; hence its peristalsis is insignificant, and consists in squeezing its contents into the tubular pre-antrum or prepyloric portion. (3) Waves of constriction along this pre-antrum force the food forward and backward through this portion until a mightier wave-impulse sweeps it into the muscular ampulla just in front of the pylorus, the antrum pylori. (4) The final expression into the duodenum is executed by the antrum, which may contract as a whole or form into two spherical muscular ventricles by a constriction (rarely). (5) A food circulation, in the sense of Beaumont and Brinton, does not occur."

**Removal of the Human Stomach.**—The first total removal of the human stomach was performed by Dr. Connor, of Cincinnati, Ohio, U. S. A., in 1885, the patient dying very soon after the operation. Langenbuch, Schuchardt, and others have also removed the stomach, and inasmuch as in these cases only a small portion was left, and that a portion which could perform no function, these cases may be regarded, from a physiologic standpoint, as complete removals. In Schuchardt's case, the patient lived two and one-half years, and was apparently in excellent health.

There are two cases, however, of complete ablation of this organ which are of great interest physiologically, and of which many important details are accessible, and these it is our purpose to describe somewhat minutely. One occurred in Zurich, Switzerland, and the other in San Francisco, California, U. S. A.



**Schlatter's Case.**—On September 6, 1897, Carl Schlatter of the University of Zurich, performed on a woman, aged fifty-six years, the operation of *esophago-enterostomy*; the patient being the subject of diffuse carcinoma of the entire stomach. In this operation the entire stomach was removed and the esophagus attached to the jejunum, it having been found impossible to approximate the esophagus and duodenum. We are indebted to the *New York Medical Record* of December 25, 1897, and March 18, 1899, for the history of this case. This article contains introductory remarks by Dr. E. C. Wendt, of New York, and a description of the operation and subsequent history of the case by Dr. Schlatter.

So completely was the stomach removed, that at the cardiac end of the extirpated organ esophageal tissue was demonstrated to be present, as was also the pylorus at the other extremity. The patient lived fourteen months after the operation, during twelve of which she was free from suffering and gained in weight. Her death was due to general cancerous infection proceeding from a carcinoma of the mesenteric lymph-glands. It is the opinion of those familiar with the case that it was not attributable in any degree to the operation nor to absence of the stomach.

Shortly after the operation an enema containing brandy and two eggs was given. The first day after the operation two enemata were administered containing milk, eggs, and brandy, and later in the day a small quantity of tea and milk by the mouth, which was retained. On the second day the enemata were not retained, and claret wine was given by the mouth. On the third day, small quantities of milk, eggs, bouillon, and wine were given by the mouth, and pepsin and hydrochloric acid. On the seventh day a little scraped meat was given, and the following day the bowels moved for the first time. Occasionally there was some regurgitation of milk, but no actual vomiting until the tenth day; on that day, and subsequently, the patient took the following food: 7 A.M., a cup of milk with one egg; 9.30 A.M., same; dinner (time not stated), very soft scraped meat or cup of thin gruel with an egg; 4 P.M., cup of milk with egg; 7.30 P.M., cup of milk or gruel. Besides these, she took tea and Malaga wine, amounting in the course of the day to from 140 c.c. to 200 c.c.

On the tenth day the patient vomited for the first time since the operation. The vomiting was preceded by nausea, and was apparently superinduced by the patient having witnessed a change of dressing in a neighboring surgical case. There was a good deal of retching, and about 200 c.c. of bilious and slightly acrid fluid were ejected. On the twentieth day she ate half a chicken, and later milk and an egg. About three hours after eating the chicken, and one hour after the milk and egg, she vomited about 280 c.c. of milk and meat-fibers. This was accompanied by retching and marked contraction of the abdominal muscles. On subsequent

days attacks of vomiting recurred. One of these was about one month after the operation, and an examination of the ejected matter showed it to be acid in reaction, due to the lactic acid, no free hydrochloric acid being found. Trypsin, bile-acids, and bile-pigments were also found.

From the time of the operation there was a continued increase in weight, as shown by the following table :

*Table showing Weight of Patient after Operation.*

Date of weighing.	Actual weight in grams.	Increase in grams.
October 5 . . . . .	33,600	
October 11 . . . . .	33,750	150
October 18 . . . . .	35,260	1510
October 25 . . . . .	35,500	240
October 29 . . . . .	36,000	500
November 5 . . . . .	36,200	200
November 19 . . . . .	36,500	300
December 3 . . . . .	37,500	1000
December 9 . . . . .	37,500	

The patient was not actually weighed on the day of the operation, but the minimum increase from September 6 to October 5 has been estimated at 2000 gm. (2 kgm.).

We cannot better conclude the history of this most remarkable and interesting case than by quoting the conclusions of Dr. Schlatter and Dr. Wendt.

Dr. Schlatter says :

*“ Clinical Observations in Connection with the Obliteration of all Gastric Functions after the Operation.—*There being no food-receptacle after ablation of the stomach, it became obligatory to feed my patient at first with minute quantities of food, given at short intervals. The results of this method of procedure were in all respects happy ones. Quantities of food approaching ten ounces seemed to excite vomiting. So, too, cold fluids resulted in diarrheal discharges, and may have been partly responsible for the rise in temperature observed for some little time after the operation.

*“ Keeping in mind the absence of mechanical function, the patient’s dietary was at first a strictly fluid one. But as early as the second week after removal of the stomach semisolid and even solid food was allowed. It was retained and digested without discomfort. The patient having only a single tooth, mastication was, of course, quite imperfect, otherwise it seems to me possible that an ordinary mixed diet might have succeeded at a still earlier date.*

*“ Some weeks after the operation the patient’s ordinary daily dietary was as follows : At regular intervals of from two to three hours she took milk, eggs, thin gruel or pap, tea, meat, rolls, butter, and Malaga wine. The daily quantity amounted to one quart of milk, two eggs, two to three ounces of pap or gruel, seven ounces of meat, seven ounces of oatmeal or barley-water*

(as thick almost as gruel), one cup of tea, two rolls, and half an ounce of butter.

“Personally I felt most concerned about the obliteration of all chemical activity on the part of the absent stomach. I soon perceived that adding pepsin and hydrochloric acid to the food was theoretically as inadmissible as it had been found practically valueless. The alkaline fluids of the intestine at once neutralized the acid, and rendered the pepsin inert.

“Fortunately, it soon became apparent that, despite the absence of acid pepsin, proteids were readily assimilated in the intestinal tract.

“*Does Gastric Acidity Influence the Decomposition of Intestinal Contents?*—This moot question received contributory elucidation by the careful study of the patient’s discharges after the operation. The urine and feces were examined every day at the chemical laboratory of the university. Products of abnormal intestinal fermentation or decomposition (skatoxyl and indoxyl) were either not at all found, or else discovered only in traces.

“These observations tend to corroborate the views of von Noorden, while they negative the opinion held by Kast and Wasbutski. The most recent results of laboratory experiments announced from Professor Baumann’s institute, viz., that hydrochloric acid inhibits intestinal decomposition, thus received no support from actual observations in the living human subject.

“*Does Removal of the Stomach Affect the Rapidity of Intestinal Propulsion?*—Observations on this point are still being made, and at the present time I am unable to present any very definite conclusions. The patient objected to swallowing charcoal. Huckleberries were at three different times found in the passages twenty-four hours after having been swallowed.

“*The Urine after the Operation.*—Apart from a daily recurring diminution in the quantity of excreted chlorids, the urine of this woman has remained normal since ablation of her stomach. The daily excretion of chlorid of sodium has been found to vary between the limits of 0.6 per cent. and 0.95 per cent. It should be stated in this connection, however, that, complying with the wish of the patient, her food is prepared with less salt than that of the other ward patients.

“*Microscopic Examination of the Feces.*—The stools were well formed, of normal consistency, and light yellow in color. The microscope showed large numbers of fat-globules, and fatty crystals, some undigested vegetable-fibers, but no undigested animal-fibers or connective tissue. Large quantities of triple phosphates were observed. The number of micro-organisms was normal. Altogether, repeated examinations revealed no noteworthy departure from a condition of perfect health.

“*Vomiting without a Stomach.*—How can a person vomit without a stomach? No matter what theoretic physiologic notions

we may have imbibed from lectures and text-books, the woman under observation had repeated attacks of ordinary nausea, retching, and vomiting. We must needs conclude, therefore, that the rôle of the stomach (*i.e.*, its antiperistaltic efficacy) in this direction has been very much overrated. While the vomited substances showed an acid reaction, this was not due to the presence of free hydrochloric acid.

"In view of the fact that the patient ejected as much as thirty ounces at one time, it seems reasonable to suppose that the remaining portion of the duodenum may have already begun to show distention sufficient to produce a sort of compensatory receptacle for food—perhaps nature's attempt in the direction of the new formation of a stomach.

"In endeavoring to explain vomiting without a stomach, we should remember that the act itself is far from being a simple process. It is due to nervous action on a complex motor apparatus, consisting of pharynx, esophagus, stomach, diaphragm, and abdominal muscles.

"It is not surprising, therefore, to have witnessed in this woman an ordinary attack of bilious vomiting superinduced by a mere physical disturbance."

*Conclusions by Dr. E. C. Wendt.*—"While it would be manifestly unfair to indulge in sweeping generalizations on the strength of this single case, so boldly rescued and ably described by Dr. Schlatter, it seems at least justifiable to formulate the following conclusions:

"1. The human stomach is not a vital organ.

"2. The digestive capacity of the human stomach has been considerably overrated.

"3. The fluids and solids constituting an ordinary mixed diet are capable of complete digestion and assimilation without the aid of the human stomach.

"4. A gain in the weight of the body may take place in spite of the total absence of gastric activity.

"5. Typical vomiting may occur without a stomach.

"6. The general health of a person need not immediately deteriorate on account of removal of the stomach.

"7. The most important office of the human stomach is to act as a reservoir for the reception, preliminary preparation, and propulsion of food and fluids. It also fulfils a useful purpose in regulating the temperature of swallowed solids and liquids.

"8. The chemical functions of the human stomach may be completely and satisfactorily performed by the other divisions of the alimentary canal.

"9. Gastric juice is hostile to the development of many micro-organisms.

"10. The free acid of normal gastric secretions has no power

**FIG. 112.—Brigham's case of removal of the stomach: patient seven weeks after the operation.**

**FIG. 113.—Anterior view of stomach removed from patient in the preceding figure (Brigham).**

to arrest putrefactive changes in the intestinal tract. Its antiseptic and bactericide potency has been overestimated."

**Brigham's Case.**—Dr. Charles B. Brigham, of San Francisco, California, on February 24, 1898, completely removed the stomach from a woman, sixty-six years of age, affected with adenocarcinoma of the stomach, involving one-half the organ, and subsequently connected the esophagus with the duodenum, thus performing the operation of *esophago-duodenostomy*. This case is described by Dr. Brigham in the *Boston Medical and Surgical Journal* of May 5, 1898, and to this journal we are indebted for the details.

In this case the operator was able to bring the duodenum up to the esophagus, which was not possible in Schlatter's case, and the two were approximated by means of a Murphy button (Fig. 114) instead of by sutures. Fig. 113 shows anterior view of the diseased organ after removal.

After the operation the patient was nourished at first by enemata of brandy and water, eggs, milk, and broths. During the evening of the day of the operation the patient vomited some bloody mucus. On the following day hot water was given by the mouth, which relieved the intense thirst. On the second day claret and water, hot black coffee or chicken-broth was given, but after two teaspoonfuls there was no desire for more. On the third day double this quantity was taken each time, and on this day the bowels were moved for the first time. The nutrient enemata were given every four hours up to the fourth day, when they were discontinued. On the sixth day she was taking about 22 c.c. at each feeding, but could take no more. This quantity, however, was gradually increased. About three weeks after the operation she took for breakfast a cup of coffee with milk, a soft-boiled egg, and a third of a baked apple; at noon, a cup of green-pea soup, a dozen small oysters, and an ounce of milk; in the afternoon, some orange-jelly, one raw egg, half a cup of pea soup, and a dozen oysters; in the evening, half a cup of asparagus soup, with 14 c.c. of whiskey and 42 c.c. of wine. During convalescence the patient vomited food once, and on another occasion some mucus. About a month after the operation she complained of hunger, and ate a squab. About ten days later she ate in one day the following: At 6.30 A.M., cup of coffee and a raw egg; at 10 A.M., two dozen small oysters and a

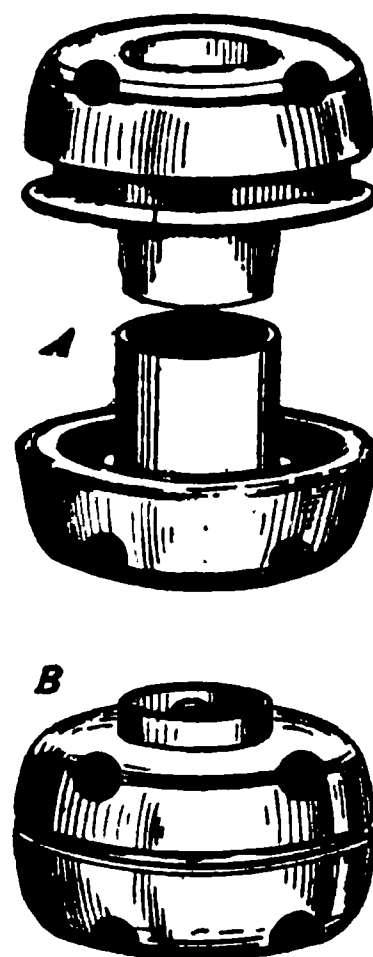


FIG. 114.—Murphy button (enlarged): A, open; B, closed.

bowl of broth ; at 1 P.M., half a broiled chicken with toast, and stewed strawberries ; at 5 P.M., half a broiled chicken, two slices of toast, and a cup of tea. During that week she gained six pounds.

In concluding the history of this case Dr. Brigham writes :

“ In the treatment of this case no attempt has been made to predigest the nourishment which was given to the patient. The precaution was taken, however, to supply easily digested food ; and when meat was allowed it was cut in very small pieces. The food was taken slowly, whether liquid or solid. It is no hardship for the patient to live on simple food, for she has done so all her life ; and especially, as age has advanced, has been obliged to eat food that required the least chewing. The food was given of medium temperature ; water was taken as it came from the pipe and wine as it stood in the room ; iced cream, of which the patient was particularly fond, was taken slowly so that it dissolved in the mouth before it was swallowed. At first everything was too salt ; as the patient got well she wished salt on both eggs and oysters. The amount of flatus in the bowels was enough to cause pain only a few times in the early part of her illness. The urine has been normal throughout. Never since the operation has any undigested food been seen in the movements from the bowels, and for the most part these have been wholly or partly formed. The patient has vomited but a few times since the operation ; twice after etherizations, twice after some laxative had been given, once after the button left its place, and twice after coughing—not more than six ounces at any one time, generally much less. On three or four occasions a mouthful of food would be regurgitated—an oyster, some shreds of meat, or a few teaspoonfuls of coffee. As a usual thing the food was well retained and well digested.”

On January 1, 1900, Dr. Brigham wrote to the author : “ I am very glad to say that Mrs. M. is in excellent health, with no sign whatever of a return of the disease. On seeing her no one would ever believe that she had undergone any surgical operation, much less the removal of the entire stomach. She returned home seven weeks after the operation ; then she took five meals a day, consisting mainly of soups, oysters, eggs, milk-toast, baked apples, stewed prunes, iced cream, and strawberries. Little by little she chose what she liked—potatoes, peas, beans, lamb-chops, chicken, and fish.

“ I have always allowed her to choose her food, thinking that the success of the operation would be the better demonstrated.

“ For nearly a year she has kept house for herself, doing all her own work ; finding ample time to visit her grandchildren, who live near by. She is now in her sixty-eighth year, and affirms that if she takes castor oil every ten days her health is perfect.

“ As to her weight, after the first year she weighed one hun-



dred and ten pounds; last summer she gained two pounds. This weight she keeps at the present time."

Since Dr. Brigham's death in 1902, the author has been unable to obtain any further history of this case.

**Achylia Gastrica.**—The fact that human beings can live and be apparently in perfect health, digesting all classes of food-stuffs, and yet possessing no stomach, as is shown most notably in Dr. Brigham's case, makes it quite easy to believe that a similar normal condition may be maintained when the stomach is present, but a stomach which secretes no gastric juice. Such a condition of permanent absence of the gastric secretion is termed *achylia gastrica*. This affection has been described also under the names *gastritis glandularis atrophicans* and progressive atrophy of the stomach. There are some cases in which the achylia is congenital, and others in which it comes on at middle life and in connection with chronic gastric catarrh or some other affection. The administration of test-meals demonstrates the absence of hydrochloric acid, pepsin, and rennin. Persons having achylia gastrica are often apparently in perfect health and eat everything they wish.

The cases in which the stomach has been totally removed, taken in conjunction with these cases of achylia gastrica, all point to the conclusion that the small intestine is capable of carrying on all the digestive processes without any aid from the stomach.

Still, it can hardly be supposed that the stomach is entirely a superfluous organ. Hemmeter, in discussing "The Logic of Hydrochloric Acid Therapy," in *American Medicine*, says:

"The cases frequently noted in patients without any gastric secretion whatever who succeed in maintaining their nitrogen-equilibrium (and we have seen many such), and the experiment on the dog (Kaiser and Czerny), the weight of which was kept up, although the largest portion of the stomach was removed, and Brigham's and Schlatter's total extirpations of the stomach, constitute but a weak argument against the therapy of HCl. For although such patients and animals manage to get along fairly well for a time, it is only under the most careful and scientific supervision that their health is maintained. Permanent and perfect health with total absence of gastric secretion is rarely observed, except in those who are able to rest much and have their food prepared with great care.

"These facts must not be overlooked in considering the work of von Noorden, which demonstrated that absolute and permanent deficiency of gastric juice may be accompanied by perfect health. This health is perfect under the conditions mentioned, but when such patients are taxed by work or the diet is not the usual one, in my experience suffering invariably becomes manifest. If achylia gastrica could really exist without any subjective or objective disturbances, how is it that so many of these patients consult the stomach specialists and are reported by them in lit-



erature? When we must work for our living and cannot have the benefit of the dietetic kitchen at all times, we must have an active gastric juice to at least partially disinfect and dissolve our food, and a person who secretes no gastric juice is or soon becomes a patient.

“In a recent article on *achylia gastrica*, by F. Martius and O. Lubarsch, the authors arrive at the conclusion that neither simple *achylia* nor that dependent upon atrophy of the mucosa (*anadenia*) can bring about severe anemic or cachectic conditions, unless motor insufficiency, atrophy of the intestinal mucosa, or general diseases (tuberculosis, lues, infections, etc.) are added. Even if this is true, generally speaking, it does not disprove the statement that absence of HCl in the gastric secretion compels the individual to lead the life of a patient, for dyspepsia and dystrypsia may exist and become severe without the anatomic changes spoken of by Martius and Lubarsch. But, over and beyond this, Flint, Fenwick, Quincke, Nothnagel, Osler, Kinnicut, also Rosenheim and G. Meyer, have described cases of pernicious anemia in which atrophy of the gastric mucosa was, at the autopsy, found to be the only organic disease existing. It is conceivable that the intestine cannot persistently digest an amount of proteid sufficient to maintain the nitrogen-equilibrium during work; that it depends upon a certain part of this proteolysis to be performed by the stomach; that the acid gastric chyme is necessary for the stimulation of the duodenal secretions. Pawlow has proved experimentally that the gastric HCl is an important stimulant to the secretion of pancreatic juice. It is probable that digestion in the duodenum is not perfect without the acid proteids, which, as we know, cause increased diastasic action of the pancreatic juice. So that we are justified in concluding on experimental and clinical grounds that in the absence of secretion of HCl in the stomach the entire duodenal digestion is abnormal.”

**Artificial Gastric Juice.**—In addition to the observations upon man and lower animals already referred to, many experiments have been carried on with an artificial gastric juice made by extracting the pepsin from the mucous membrane of the stomach of the pig with glycerin, and adding to this glycerin-extract 0.2 per cent. of hydrochloric acid. The results of these experiments are, however, not to be regarded as identical with those that take place in the stomach of a living being. The factors in the problem are many, and some of them are still undetermined.

**Effect of Alcohol on Digestion.**—This subject has already been fully discussed, and the reader is referred to p. 159.

## INTESTINAL DIGESTION.

The intestinal canal extends from the stomach to the anus, and is divided into the duodenum, jejunum, and ileum, which constitute the small intestine, which is about 8 meters in length, and the cecum, colon, and rectum, constituting the large intestine, having together a length of 1.68 meters.

**Structure of the Small Intestine.**—The duodenum is the portion of the small intestine into which the food enters after leaving the stomach. It is about 30 cm. in length and 5 cm. in diameter, and passes into the jejunum, and this in turn into the ileum, the opening between the ileum and the beginning of the large intestine being guarded by the ileocecal valve.

**Coats of the Small Intestine.**—Like the stomach, the small intestine is composed of four coats: 1, serous; 2, muscular; 3, submucous; 4, mucous. As in the stomach, the two coats which have special physiologic interest are the *muscular* and the *mucous*. The *muscular* coat is made up of two layers: an external or longitudinal and an inner or circular, between which are lymphatic vessels and the *plexus myentericus* of Auerbach (Fig. 115).

In the *submucous* coat are blood-vessels, lymphatics, and the plexus of Meissner.

FIG. 115.—A portion of the plexus of Auerbach from stomach of cat, stained with methylene-blue (*intra vitam*), as seen under low magnification (Huber).

The *mucous*, or most internal, coat contains the following structures, a knowledge of which is essential to an understanding of the physiology of this portion of the digestive apparatus: (1) *valvulae conniventes*; (2) villi; (3) glands of Brunner; (4) glands of Lieberkühn; (5) solitary glands; (6) agminated glands or Peyer's patches.

*Valvulae Conniventes.*—The mucous coat of the intestine is arranged in folds, to which the name *valvulae conniventes* has been given (Fig. 116). These folds, which begin about 2 cm. below the pylorus, are present throughout the length of the small intestine, excepting in the lower part of the ileum. They are more abundant in the upper half of the intestine, where they have been counted to the number of 600, than in the lower half, where only 250 have been found, making about 850 in all. These folds are arranged around the interior of the intestine at right angles to its long axis. They do not completely encircle it like a ring, but vary in length, some extending about two-thirds and others only one-third the distance around. The widest of them is not more than 1.5 cm. in width, projecting into the caliber of the intestine to this extent. Each is a double fold of mucous membrane with connective tissue between, which so binds the folds together that even in the condition of distention the *valvulae conniventes* are not obliterated, as

FIG. 116.—Portion of the wall of the small intestine, laid open to show the *valvulae conniventes* (Brinton).

FIG. 117. Mucous membrane of the jejunum, highly magnified (schematic): 1, 1, intestinal villi; 2, 2, closed or solitary follicles; 3, 3, orifices of the follicles of Lieberkühn (Testut).

is the case with the *rugae* of the stomach. By means of these foldings the extent of the mucous membrane is greatly increased over what it would be did it simply line the intestine.

*Villi.*—Projecting from the mucous membrane including the

valvulae conniventes are the *villi* (Fig. 117), which are so numerous as to give to it a velvety appearance. Between them open the glands of Lieberkühn. The villi are prominences, some triangular, some conical, and some filiform in shape, and in length are about 0.5 to 0.7 mm., and in width at their base about one-fourth their length (Fig. 118). They are most numerous in the duodenum and the jejunum, although present throughout the whole extent of the

Epithelium  
of villus.

a

Epithelium  
of villus.

Goblet-cell.

Gland (crypt)  
of Lieber-  
kühn.

Mucosa.

Muscularis  
mucosae.

FIG. 118.—Section through mucous membrane of human small intestine;  $\times 88$ : at a is a collapsed chyle-vessel in the axis of the villus (Böhm and Davidoff).

small intestine. It has been estimated that there are no less than 4,000,000 of these villi in an intestine.

Each villus is composed of retiform tissue, and is covered with a single layer of columnar epithelium resting upon a *basement-membrane* consisting of a layer of endothelial cells. Between the cells of columnar epithelium, at their bases and in the retiform tissue, are numerous lymph-corpuscles. Between adjoining epithelial cells and also between the endothelial cells is interstitial

cement-substance, and the reticulum of the matrix of the villus is continuous from the interior of the villus through this interstitial substance to its exterior. Next the basement-membrane is a *plexus of capillary blood-vessels*. Still more interior is *muscular tissue*, a part of the muscularis mucosæ, while the central structure of all is a *lacteal*.

The capillary plexus, muscular tissue, and lacteal are surrounded by reticular tissue constituting the matrix of the villus, and in the interstices of this are lymph-corpuscles and the *cells of*

a                      b      c      d

FIG. 119.—Longitudinal section through summit of villus from human small intestine;  $\times 900$  (Flemming's solution): at a is the tissue of the villus axis; b, epithelial cells; c, goblet-cell; d, cuticular zone (Böhm and Davidoff).

*the villus*; large, flat cells with oval nuclei. If the components of a villus are named in the reverse order to that just given, we shall have, starting from the center, (1) lacteal, (2) muscular tissue, (3) capillary plexus, (4) basement-membrane, (5) columnar epithelium. The lacteals are single in some of the villi and in others double. Their walls consist of a single layer of endothelium, and the cement-substance between the cells is continuous with the reticular tissue composing the matrix. It will be seen, therefore, that from the lacteal to the surface of the villus there is continuous reticular tissue. This is regarded by Dr. Watney as the path

which the particles of fat take when they are undergoing the process of absorption (p. 261)—*i. e.*, from the lumen of the intestine (1) through the interstitial or cement-substance of the columnar epithelium; (2) through the same substance in the basement-membrane; (3) through the reticulum of the matrix; (4) through the interstitial substance of the lacteals into the interior of this structure.

The lacteals are the lymphatic vessels of the small intestine,

Epithe-  
lium of  
villus.

Vein of  
villus.

Artery of  
villus.

Gland of  
Lieber-  
kühn.  
Base of  
villus.

Artery.

Vein.

serous coat.

FIG. 120.—Schematic transverse section of the human small intestine (after F. P. Mall).

which, on leaving the villi, form a plexus in the mucous and sub-mucous tissue, and discharge into larger lymphatic vessels, and their contents finally pass into the thoracic duct.

*Brunner's Glands* (Fig. 121).—In the submucous coat of the upper part of the duodenum, and to a less extent in that of the lower part, and in the beginning of the jejunum, are certain glands known as the *glands of Brunner*, or the *duodenal glands*. These are tubulo-racemose glands, similar to the lobules of a salivary gland. They discharge through ducts which open upon the sur-

face of the mucous membrane of the intestine. Their secretion is mucus having a slightly alkaline reaction, but it has never been successfully obtained so pure as to admit of its being analyzed. These glands are so few in number, comparatively, that their product cannot be very abundant nor very important in its action upon the food, although an enzyme has been described as one of its constituents which has the power of converting maltose into glucose. The secretion of the glands, together with that of the follicles of Lieberkühn, constitutes the intestinal juice. These glands are inflamed and ulcerate whenever the body is burned to any great extent.

*Follicles of Lieberkühn.*—The follicles or crypts of Lieberkühn, which are found throughout the entire length of the small intestine, are simple tubular glands in the mucous membrane, and not beneath it, as is the case with the glands of Brunner. They are lined with a layer of columnar epithelium similar to that which covers the surface of the mucous membrane and the villi (Fig. 122).

FIG. 121.—Vertical section of duodenum, showing villi (a); crypts of Lieberkühn (b), and Brunner's glands (c) in the submucosa (s), with ducts (d); muscularis mucosae (m), and circular muscular coat (f) (Schofield).

*Solitary and Agminated Glands.*—The solitary glands are found in the mucous membrane of the whole small intestine, in greater number, however, in the lower part of the ileum. They have a diameter of from 3 to 6 mm., and present a round and somewhat prominent appearance. They are

composed of lymphoid tissue, and contain many lymph-corpuscles. They have no duct, and their product probably oozes through the walls of the glands and contributes something to the intestinal juice. When these glands are aggregated they form patches, and are called *agminated glands* or *Peyer's patches* (Fig. 123).

These are about twenty-five in number, though in youth as many as forty-five have been seen, while in old age they are absent. They occur principally in the ileum, though they are also found in the lower part of the jejunum, where they are much smaller and circular, and sometimes in the lower part of the duodenum. These patches vary in length from 1.5 cm. to 10 cm., and in width from 4 cm. to 5 cm. Like the solitary glands, they are with-

out ducts, and their secretion finds an exit in the same manner. In typhoid fever they become inflamed and often undergo ulceration.

**Structure of the Large Intestine.**—The coats of this portion of the alimentary canal are the same in number and kind as those of the small intestine, although the arrangement of the longitudinal fibers of the muscular coat is in some portions in the

epithe-

gland.

1.

s

FIG. 122.—From colon of man, showing glands of Lieberkühn;  $\times 200$  (Böhm and Davidoff).

form of bands, a quite different arrangement from that in the small intestine. At the anus the circular fibers constitute the *internal sphincter*.

The mucous membrane contains both solitary glands (Fig. 117) and glands which resemble the follicles of Lieberkühn, and indeed are called by that name by some writers (Fig. 122); still the secretion differs very materially, not containing any enzymes



possessing digestive powers. The epithelium contains mucus-secreting or goblet-cells, and their product is principally mucus.

**Succus Entericus or Intestinal Juice.**—This is the secretion of all the glands of the small intestine; but the follicles of Lieberkühn, being vastly more numerous than the others, contribute by far the greater part of the fluid. It is obtained from animals by making a "Thiry-Vella fistula." This consists in cutting out a piece of intestine, from 10 to 30 cm. long, without interfering with its nerves or blood-supply, and sewing the open ends to two openings in the abdominal wall. The severed ends of the intestine, from which the piece has been isolated, are also

sewn together. The fluid obtained from the portion thus isolated is pure intestinal juice, without admixture with food or other substances. This operation has been performed on the dog, and the juice obtained is described as being limpid, yellowish, having a specific gravity of 1010, and a strongly alkaline reaction, due to the presence of sodium carbonate.

The fluid has also been obtained from a human being, from a piece of intestine 9 cm. long, situated about 20 cm. above the ileocecal valve. The daily product averaged 27 c.c. The specific gravity averaged about 1007.

FIG. 123.—Mucous membrane of the jejunum (Testut): 1, Peyer's patch; 2, its border; 3, solitary follicles; 4, 4, *valvulae conniventes*.

The fluid was opalescent and often of a brownish color. It was always alkaline, and when treated with acids carbonic acid gas was evolved. It gave all the proteid reactions, but did not reduce Fehling's solution or change the color of a solution of iodine.

**Action of Intestinal Juice.**—Although the chemical composition of this fluid is not well understood, it is, nevertheless, known to possess several enzymes: amylolytic, sugar-splitting, and activating (p. 119). The amylolytic enzyme changes starch to maltose, and possibly some dextrose. It has been claimed that the maltose is converted into glucose by the product of Peyer's patches. Another enzyme, *invertin* or *invertase*, changes saccharose into dextrose and levulose. The changes undergone in this process have been already described (p. 93). The succus entericus contains no proteolytic enzyme, nor is fat split up by it. Its alkalinity aids in the emulsification of fats. The activating enzyme is enterokinase, which changes trypsinogen into trypsin.

From the above considerations the intestinal juice must be regarded as possessing some digestive action upon the food-stuffs, its most marked property being its power of inversion. It is

Epithelium  
of intes-  
tine.  
a

Germ  
center

Submu-  
cosa.

FIG. 124.—A solitary lymph-nodule from the human colon: at *a* is seen the pronounced concentric arrangement of the lymph-cells (Böhm and Davidoff).

not an abundant secretion, and one of its important offices is, doubtless, to lubricate the mucous membrane of the small intestine.

### THE PANCREAS.

**Structure of the Pancreas.**—This organ is a gland of the tubulo-racemose type, and, from its resemblance to the salivary glands, is described as the abdominal salivary gland; the pancreatic alveoli are, however, longer and more tubular. Its location is in the abdominal cavity, behind the stomach and between the duodenum and the spleen. Its length is from 15 to 23 cm., its width about 4.5 cm., and its thickness 2.8 cm. The alveoli are lined with columnar or polyhedral cells, which, in the fresh condition, contain small granules in the protoplasm of their inner two-thirds, while that of the outer third is clear. This clear portion becomes larger, encroaching upon the granular part, when the gland is active.

The changes which these cells undergo may be more distinctly shown by means of carmine, which acts as a staining agent. Thus Fig. 125 represents the appearance of the cells of a pancreas which was removed from a dog that had fasted for twenty-four hours.

The gland was hardened in alcohol and a section of it was stained with carmine. The clear portion at the base of the cells takes the stain better than the more granular, internal portion. Fig.

FIG. 125.—Pancreas of dog during hunger; preserved in alcohol and stained in carmine (after Heidenhain).

126 represents a section from a dog that had been fed from six to ten hours before the gland was removed; the encroachment of the clear upon the granular portion is shown by the greater width of

FIG. 126.—Pancreas of dog during first stage of digestion; alcohol, carmine (after Heidenhain).

the stained zone. In other words, the granules are being used up to form these products, the enzymes. Fig. 128 represents the cells when they have returned to a condition of rest.

FIG. 127.—Pancreas of dog during second stage of digestion; alcohol, carmine (after Heidenhain).

In the connective tissue are groups or islets of epithelium-like cells (Figs. 129, 130), which are supposed to produce the internal secretion of the pancreas (p. 239).

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|  
|

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FIG. 128.—From section through human pancreas;  $\times 450$  (sublimite) (Böhm and Davidoff).

**Pancreatic Juice.**—The most important changes which the food undergoes in the process of intestinal digestion are those which are due to the action of the pancreatic juice. This is the



FIG. 129.—From section through human pancreas.  $\times$  about 200 (sublimato) (Böhm and Davidoff).

product of the pancreas, and reaches the intestine by means of the pancreatic duct which, together with the common bile-duct, opens into the duodenum about 8 to 10 cm. below the pylorus.

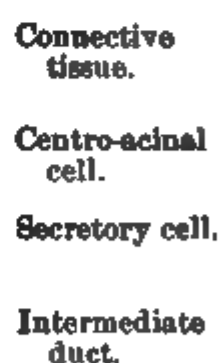


FIG. 130.—Scheme showing relation of three adjoining alveoli to excretory duct, illustrating origin of centro-acinal cells (Böhm and Davidoff).

**Quantity of Pancreatic Juice.**—The amount of this fluid secreted daily in the human being is not known, but it has been found that in the dog it is 2.5 grams per kilo of body-weight. This would give in a man weighing 70 kilos, 175 grams daily.

**Composition of Pancreatic Juice.**—The pancreatic juice has been obtained repeatedly from the dog and the rabbit by the operation of establishing a permanent pancreatic fistula. For this purpose that portion of the duodenum of a rabbit into which the main duct discharges, which in this animal is about 35 cm. below the

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FIG. 131.—Stomach in place after removal of liver and mass of intestines: *A*, diaphragm; *B*, *B'*, thoraco-abdominal wall; *C*, right kidney with *c*, its ureter; *D*, right suprarenal capsule; *E*, left kidney with *e*, its ureter; *F*, spleen; *G*, aponeuroses of transversales; *H*, *H'*, quadrati lumborum; *I*, *I'*, psoas muscles; *K*, esophagus; *L*, stomach; *M*, duodenum. 1, cardia; 2, greater curvature; 3, lesser curvature; 4, great tuberosity or fundus; 5, small tuberosity or antrum of pylorus; 6, pylorus; 7, right vagus; left vagus; 9, thoracic aorta; 9', abdominal aorta; 10, inferior diaphragmatic arteries; 11, celiac axis; 12, hepatic artery; 13, right gastro-epiploic; 14, coronary artery; 15, splenic artery; 16, 16', superior mesenteric artery and vein; 17, inferior mesenteric artery; 18, spermatic artery; 19, gall-bladder; 20, cystic duct; 21, hepatic duct; 22, inferior vena cava; 23, portal vein; 24, great sympathetic (Testut).

opening of the bile-duct, is opened and a glass cannula is introduced into the duct and the secretion collected as it escapes. The amount thus obtained from rabbits is very small; it is clear, colorless, alkaline, and does not clot. That obtained from fistulæ in dogs is thicker, and coagulates on standing, although it is less thick after the fistulæ have existed for some time. The specific gravity,

FIG 132.—Excretory ducts of the pancreas *A*, pancreas, with *a*, its head; *B*, duodenum; *C*, jejunum; *D*, gall-bladder. 1, main pancreatic duct of Wirsung; 2, accessory duct with 2', its opening upon the postero-internal wall of the duodenum; 3, ampulla of Vater; 4, common bile-duct; 5, cystic duct; 6, hepatic duct; 7, aorta; 8, superior mesenteric vessels; 9, celiac axis with its three branches (Testut).

too, falls from 1030 to 1010. The following table gives its composition :

*Pancreatic Juice of Dog (C. Schmidt).*

CONSTITUENTS.	Immediately after establishing fistula.	From permanent fistula.
Water . . . . .	900.76	980.45
Solids . . . . .	99.24	19.55
Organic substances . . . . .	90.44	12.71
Ash . . . . .	8.80	6.84
Sodium carbonate . . . . .	0.58	3.81
Sodium chlorid . . . . .	7.25	2.50
Calcium, magnesium, and sodium phosphates . . . . .	0.58	0.08

Less is known as to the chemical composition of human pancreatic juice. Herter obtained the fluid from an enlarged duct caused by carcinoma of the duodenum. In 1000 parts of this there were 24.1 parts of total solids, 17.8 parts of organic matter, and 6.2 parts of ash. Zadawsky obtained the juice from a young woman

from whom a tumor of the pancreas had been removed. The analysis of this was as follows :

Water . . . . .	864.05
Proteids . . . . .	92.05
Other organic substances . . . . .	40.46
Salts . . . . .	3.44

**Enzymes of Pancreatic Juice.**—It is a remarkable fact that the pancreatic juice of all vertebrates, so far as examined, contains four enzymes : (1) amylolytic, (2) proteolytic, (3) fat-splitting, and (4) milk-curdling.

*Amylopsin.*—This is the amylolytic enzyme of the pancreatic juice, and is regarded as identical with ptyalin of the saliva, although pancreatic juice has much greater amylolytic power than saliva, and acts upon uncooked starch ; but whether this is due to a difference in the enzymes or because in pancreatic juice the enzyme is more concentrated, has not been determined. Some authorities include them both under the name of ptyalin.

Amylopsin appears in the pancreatic juice for the first time about one month after birth, while ptyalin is present in the human parotid gland at birth, but in the submaxillary gland not until about two months subsequently.

The optimum temperature for amylopsin is from 30° C. to 45° C., while between 60° C. and 70° C. it is destroyed. Its activity is greatest when the reaction is neutral or when a minute trace of acid is present, such as, for instance, 0.01 per cent. of hydrochloric acid. Its action on starch is to change it to maltose and dextrose, or, under some circumstances, to maltose alone. Authorities who regard the action of saliva upon starch as being of comparatively little importance look to amylopsin and to the amylolytic enzyme of the intestinal juice as the principal agents in starch conversion. This we regard as a mistake, and are inclined to place a much higher value upon salivary digestion than do these, but at the same time would give pre-eminence to the pancreatic juice as a starch converter.

*Trypsin.*—This is the proteolytic enzyme of the pancreatic juice, and its power in this regard is greater than that of pepsin. It has been found in the pancreatic juice during the last third of fetal life. Its activity is greatest when sodium carbonate is present to the amount of about 1 per cent., although it acts when the reaction is neutral or very slightly acid. When hydrochloric acid is present to any considerable extent the enzyme is destroyed, and this is hastened when pepsin is also present.

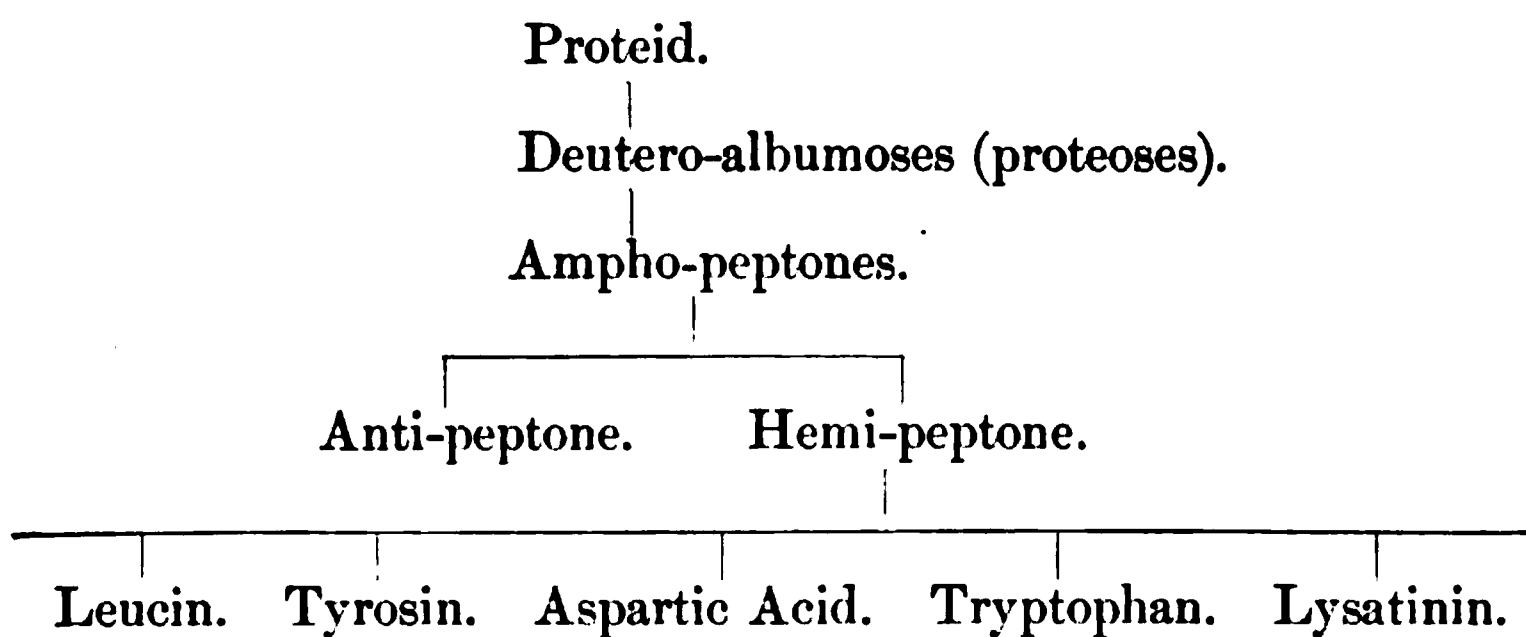
Trypsin has never been isolated, so that its chemical composition has not as yet been determined. In the action of the cells of the pancreas, the zymogen trypsinogen is first formed, and this later becomes trypsin. In studying its action, a pancreas



may be cut up finely and the enzyme extracted with glycerin, to which extract a solution of sodium carbonate of from 0.2 to 0.5 per cent. is added. Inasmuch as the pancreas and its extracts undergo putrefaction very readily, the glycerin preparation may be preserved by the addition of a few drops of an alcoholic solution of thymol.

*Tryptic Digestion.*—The differences between peptic and tryptic digestion are quite marked. Pepsin requires an acid medium; trypsin acts best in one that is alkaline. When peptic digestion of a solid proteid occurs, this first swells up and then gradually dissolves, while in tryptic digestion there is no preliminary swelling of the proteid, but the erosion begins at once. In peptic digestion the proteid first becomes acid-albumin, then passes into the stage of primary proteoses, followed by that of secondary proteoses, and finally becomes peptones. In tryptic digestion it passes at once into the stage of secondary proteoses, and then on into peptones. These peptones are spoken of as amphopeptones, because there are at least two of them, anti-peptone and hemi-peptone. The action of pepsin stops when these are formed, but trypsin can act still further by splitting up the hemi-peptone into a number of substances, among them leucin, tyrosin, aspartic acid, tryptophan, and lysatinin. What office these substances have in the body, if any, is as yet undetermined, though it is probable that a portion of the urea found in the body is derived from lysatinin, and Halliburton states that “recent research indicates that even the simple cleavage products (leucin, tyrosin, etc.) may also be utilized for the synthetic production of proteids.

The changes which proteids undergo in tryptic digestion are well shown in the following scheme of Neumeister :



*Steapsin.*—The fat-splitting or lipolytic enzyme of the pancreatic juice, steapsin, is sometimes termed *pialyn*. Its action has already been described in connection with saponification (p. 100), and consists in the taking up of water by the neutral fats, which then “split up,” glycerin and a free fatty acid being the result.

The evidence that the pancreatic juice has this power is unquestioned, and that it is due to the presence of an enzyme is proved by the fact that boiling destroys this power, and by the further fact that it cannot be due to bacteria, for antiseptics do not affect it; nevertheless, the knowledge as to its properties is very meager. Its action upon fats is very rapid, and it is probable that "it is capable of splitting up all the fat of a full meal in the ordinary time of digestion within the body." The presence of bile, by virtue of its contained bile-salts or bile-acids, increases its activity, and this is still greater when hydrochloric acid is present.

An interesting fact in connection with the secretion of the pancreatic juice is that its composition varies according to the nature of the food ingested. Thus, if fat is present in considerable quantity, there will be produced a corresponding amount of the lipolytic enzyme, whereas if the diet consists largely of muscular tissue, trypsin will preponderate. There is no reason to believe that this variation in the composition of digestive juices is confined to the pancreas; it is doubtless equally true of other digestive organs that their products vary with the character of the food.

*Emulsifying Power of Pancreatic Juice.*—One of the offices performed by the pancreatic juice is to make an emulsion of fats which form an important part of the food. This action is not due to any enzyme, but to the formation of fatty acids by the steapsin; indeed, this is regarded by some authorities as the chief office of the lipolytic enzyme. The splitting up of fat is in and of itself, according to this theory, of no great physiologic importance, inasmuch as only a part of the fat is thus split up, but the fatty acids which result, together with the fatty acids which the fats themselves contain, bring about the emulsification of the main portion of the fat, which process is, according to some authorities, so essential in preparing it for absorption. Of the theories propounded to explain fat absorption, we shall speak later (p. 261).

The fatty acids resulting from the decomposition of the fat unite with the alkaline salts in the small intestine, probably those of the bile and the intestinal juice rather than those of the pancreatic juice, and form soaps, which, aided by the peristaltic movements of the intestine, convert the fat into an emulsion. The proteids of the pancreatic juice take no part in this emulsifying process, but it is very materially aided by the presence of the bile, inasmuch as bile and pancreatic juice acting together split up fat much more quickly than the juice alone.

In what manner soaps act to emulsify fats is not known. Some have supposed that the soap forms a film around the fat-globules after they have been finely divided, which prevents their uniting; but the formation of such a film has never been demonstrated. Moore, in Schäfer's *Physiology*, says that the very fine subdivision of the fat and the increased viscosity of the menstruum occasioned

by the dissolved soap, are quite sufficient to explain the permanency of emulsions of fat.

*Milk-curdling Enzyme of the Pancreatic Juice.*—Milk, to which an extract of the pancreas has been added, coagulates, and the term *pancreatic casein* has been applied to this precipitate. It is probably a substance intermediate between casein and caseinogen. The coagulating agent is considered to be an enzyme, though nothing definite is known about it.

**Innervation of the Pancreas.**—The nerves which supply this organ are from the celiac plexus of the sympathetic, together with some fibers from the right vagus, and are non-medullated and gangliated. When food enters the stomach of a dog, almost immediately the secretion of pancreatic juice begins, and is at a maximum in from one to three hours. It then diminishes until about five or six hours after the meal is taken, when it again increases until the ninth or eleventh hour, and again diminishes until the sixteenth or seventeenth hour, when it is practically *nil*. Fig. 133 shows this in the dog. Just what the facts are in man is unknown, although it is believed that the secretion begins about the time of entrance of food into the stomach; but its increase and

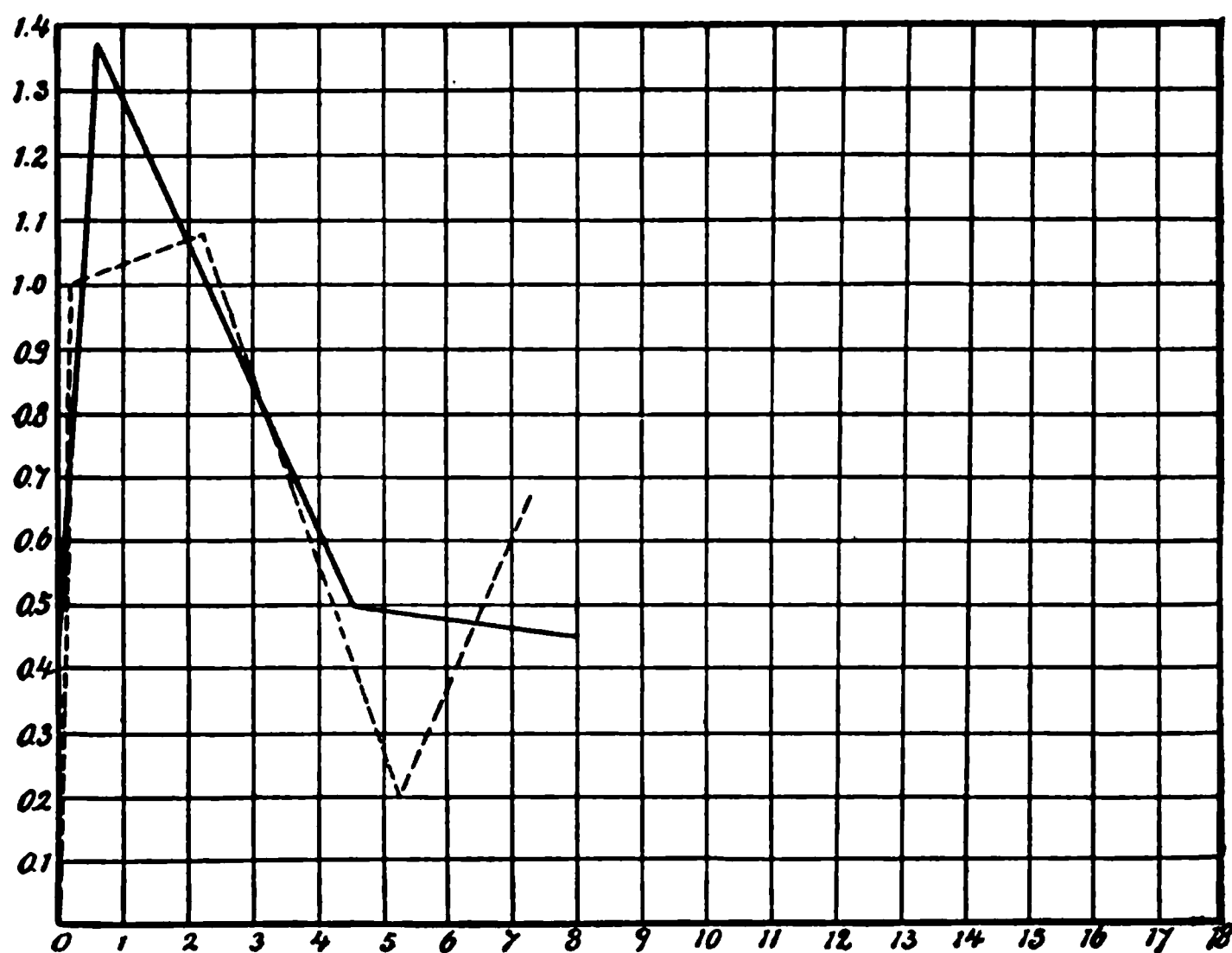


FIG. 133.—Curve of the secretion of pancreatic juice during digestion. The figures along the abscissa represent hours after the beginning of digestion: the figures along the ordinate represent the quantity of this secretion in cubic centimeters. Curves of two experiments are given (after Heidenhain).

diminution would, doubtless, vary very materially from those of the dog, which was fed but once during the day.

Formerly it was considered that the secretion of pancreatic juice is a reflex act brought about by stimulation of the afferent fibers of the mucous membrane of the stomach or intestine, or both, by the gastric juice, but, according to Bayliss and Sterling, it is due to the production by the duodenal glands, as a result of the action of the gastric juice, of a substance termed by them *secretin*, which is taken up by the blood and, being carried to the pancreas, stimulates that gland to the secretion of the pancreatic juice.

Fleig claims that the soaps formed in the small intestine as a result of the saponification of the fats of the food, produce by their action on the mucous membrane *sapokrinin*, which is absorbed and carried to the pancreas by the blood, where it stimulates that gland, thus aiding in the secretion of pancreatic juice.

**Internal Secretion of the Pancreas.**—This organ has been removed from animals without producing an immediately fatal result, but in every such case sugar has appeared in the urine, producing a condition denominated *glycosuria*, and this, too, when no carbohydrate was present in the food. The urine has also been increased in quantity, thirst and hunger have been marked, and emaciation and muscular weakness have set in, with death resulting in one or two weeks. If the gland is not entirely removed, so little as one-fourth or one-fifth being left, glycosuria does not occur, and, what is still more remarkable is, that after the removal of the gland, if a portion of it is grafted under the skin, or if the ducts are closed so as to prevent the secretion from entering the duodenum, glycosuria is also absent. All of which goes to prove that besides the pancreatic juice, which may be regarded as the external secretion of the pancreas, it also produces an internal secretion which, taken up by the blood or lymph, either aids in destroying the sugar produced by the liver or muscles, or else inhibits the glycogenic function of these organs. The cells which are believed to form this secretion have been described in connection with the pancreas (p. 231).

## THE LIVER.

This organ is situated in the abdominal cavity, and is as large as all the other glands of the body taken together. Its transverse diameter is 28 cm., anteroposterior diameter, 20 cm., and vertical diameter, 6 cm. (Fig. 134). Its blood-supply is from the portal vein and hepatic artery, while its nervous supply is from the left vagus and celiac plexus. It is covered by the peritoneum, and beneath this is the fibrous coat, which, at the transverse fissure, is continuous with *Glisson's capsule*. This connective-tissue envelope covers the hepatic artery, portal vein, and hepatic duct, and accompanies them through passages in the liver, the *portal canals*.

**Chemical Composition.**—The liver during life is alkaline,

but after death becomes acid, owing to the formation of sarcolactic acid.

Its percentage-analysis is as follows (von Bibra):

Water . . . . .	76.17	Gelatin . . . . .	3.87
Insoluble tissues . . . . .	9.44	Extractives . . . . .	2.40
Proteids . . . . .	2.40	Fats . . . . .	2.50
Inorganic constituents . . . . .	1.10		

**Proteids.**—These are a globulin (cell-globulin) coagulating at 45° to 50° C.; another globulin, coagulating at 70° C.; a nucleoproteid coagulating at about 60° C., which, when injected into the blood-vessels, causes coagulation of the blood; and an albumin.

	Non-peritoneal surface.
Gastric surface.	Imp. supra-ren. (non-perit).
Tuber papillare.	Imp. supra-ren. Impressio renalis.
Tuber omentale.	Imp. duodenalis.
	Impressio celica.

Impressio pylorica.

FIG. 134.—Posterior and inferior surfaces of the liver.

**Extractives.**—These are urea, uric acid, xanthin, hypoxanthin, and *jecorin*. This last constituent contains phosphorus, and has the following formula:  $C_{105}H_{138}N_5SP_3O_{45}$ . It resembles lecithin, but, unlike that substance, reduces Fehling's solution. It is not confined to the liver, but is also found in the spleen, muscle, and brain. The liver also contains a nuclein, with which iron is in combination, called *Zaleski's hepatin* and also *Schmiedeleberg's ferratin*. Iron is present in the liver of young animals in greater proportion than in old ones, and it is stated that animals are born with iron in both liver and spleen. This iron meets the demand of the body until the use of milk is given up, this fluid being poor in iron.

**Structure.**—The liver is made up of five lobes, which are composed of lobules each having a diameter of about 1 mm., and these in turn contain hepatic cells, polyhedral in shape, the secreting elements of the liver, each having a diameter of about  $\frac{1}{10}$  mm., and containing a nucleus. The protoplasm contains glycogen and iron-containing pigment-granules, and may also contain fat. Nerve-fibers are described by some histologists as terminating between the cells, but not passing into their interior. The lobules are separated by connective tissue, which is abundant in the pig, but much less so in man.

**Hepatic Artery.**—The hepatic artery is a branch of the celiac axis, and enters the liver at the transverse fissure, dividing here into two branches, right and left, which go to the corresponding lobes. This artery furnishes nutrition to the coats of the large blood-vessels, the ducts, the membranes of the liver, and to Glisson's capsule. It also gives off branches, *interlobular branches*, which pass between the lobules and give off *lobular branches*. These enter the lobules and end in a capillary network between the cells. Whether, however, any blood is carried by these vessels directly to the network is in dispute.

**Portal Vein.**—This vessel also enters the liver at the transverse fissure, dividing into two, each branch going to the corresponding lobe, and following the course already described as being taken by the hepatic artery and its branches. The termination

Portal interlobular branch, cut longitudinally.

The same, cut transversely.

be-  
res-  
1  
2.

FIG. 135.—Section through injected liver of rabbit. The boundaries of the lobules are indistinct;  $\times$  about 35 (Böhm and Davidoff).

of the portal vein forms the *interlobular plexus*, which, as its name implies, is in the connective tissue, between the lobules. From this go off vessels which run to the center of the lobule, being connected by transverse vessels, the whole forming a capillary network, in the meshes of which are the hepatic cells. The blood which passes through this network is discharged at the center of the lobule into the *intralobular* or *central vein*, which, at the base of the lobule, enters the *sublobular vein*. In a similar

manner all the intralobular veins discharge, and the sublobular veins unite to form larger veins, which terminate in the hepatic veins, which, as three large trunks and some small ones, discharge into the vena cava, at the back of the liver.

**Hepatic Duct.**—Between adjoining hepatic cells are small passages, *intercellular biliary passages* or *bile-canaliculi*, which are the beginnings of the hepatic duct (Fig. 137). It would be more correct to say that the beginnings of the hepatic duct are within the hepatic cells themselves, for it has been demonstrated that in the interior of these cells are vacuoles which communicate with the bile-canaliculi (Fig. 137). The canaliculi pass outward to the interlobular spaces, where they form an *interlobular biliary plexus*, from which ducts are given off that enter the portal canals, and, covered with Glisson's capsule, in company with the branches of

Intralobular  
vein.

Branch of  
portal vein.  
Bile-duct.

Branch of  
hepatic  
artery.  
Interlobular  
connective  
tissue.

FIG. 136.—Section through liver of pig, showing chains of liver-cells;  $\times 70$  (Böhm and Davidoff).

the portal vein and hepatic artery, they emerge from the liver at the transverse fissure as two trunks, right and left, which unite to form the hepatic duct. This is from 3 to 5 cm. in length and has a diameter of about 4 mm. The bile-canaliculi have no wall save such as is made by the hepatic cells. The interlobular ducts have a wall of connective tissue lined with columnar epithelium. In the larger duct is fibrous and plain muscular tissue. The ducts in the portal canals have opening into them *cecal diverticula*, which are regarded by Sappey as mucous glands.

**Gall-bladder.**—The gall-bladder lies on the under surface of the liver in the *fossa vesicalis*, being attached thereto by vessels and connective tissue. The neck of the gall-bladder terminates in the *cystic duct*, which is spiral in form, and unites with the

hepatic duct to form the *ductus choledochus* or *common bile-duct*. The cystic duct, from the neck of the gall-bladder to its union with the hepatic duct, is 3 to 7 cm. long, and has a diameter of 2.3 mm. The length of the common bile-duct depends upon the point at which the cystic and hepatic ducts unite, which is not

FIG. 137.—Diagram of a segment of an hepatic lobule: 1, 1, interlobular portal vein; 2, central vein; 3, 3, intralobular capillaries; 4, 4, interlobular hepatic artery; 5, 5, ramifications of hepatic artery, contributing to the formation of the intralobular capillaries; 6, 6, interlobular bile-duct; 7, 7, its ramifications in the lobule, forming a plexus of intercellular canaliculi; 8, 8, section of biliary canaliculi with their intercellular capillaries; 9, 9, hepatic cells; 10, 10, interlobular lymphatics, receiving the intralobular lymphatics; 11, 11, 12, intralobular connective tissue (Testut).

uniform. The following measurements are given: 7 to 8 cm. (Sappey); 2 to 4.5 cm. (Luschka); 6 to 7 cm. (Joessel). Its diameter is from 5.6 mm. to 7.5 mm.

The coats of the gall-bladder are three: *serous* or peritoneal; *fibro-muscular*, made up of fibrous tissue with plain muscular fibers arranged both longitudinally and transversely, the former greatly predominating; and *mucous*. This last, which forms the



internal coat, presents a honey-comb appearance. It is covered with columnar epithelium. The mucous membrane of the cystic duct forms folds which bear some resemblance to the *valvulae conniventes* of the small intestine. These folds are called *valvula Heisteri* or the *valve of Heister*. The mucous membrane is continuous with that lining the hepatic and common bile-duct.

**Bile.**—This is one of the products of the cells of the liver; as it is secreted it passes through the hepatic and cystic ducts into the gall-bladder, where it is stored until needed at the time of intestinal digestion, when it is discharged through the common bile-duct into the duodenum by an opening common to it and the pancreatic duct.

**Properties of Bile.**—The bile is a constant secretion—*i. e.*, the liver-cells are constantly producing it, although it leaves the liver

**FIG. 138.**—View of duodenum and pancreas. The part of stomach removed is indicated by dotted lines; *A*, quadrate lobe; *B*, right kidney; *C*, *C'*, right and left suprarenal capsules; *D*, left kidney; *E*, pancreas; *F*, upper part of stomach; *G*, spleen; *H*, duodenum, with *a, b, c, d, e*, its five parts; *I*, jejunum; *K*, duodeno-jejunal angle. 1, lower end of esophagus; 2, pyloric orifice; 3, celiac axis; 4, coronary artery; 5, hepatic artery; 6, Spigelian lobe of liver; 7, 7', splenic vessels; 8, left gastro-epiploic artery; 9, right gastro-epiploic artery; 10, superior mesenteric vessels; 11, portal vein; 12, hepatic duct; 13, cystic duct; 14, gall-bladder; 15, left crus of diaphragm; 16, aorta; 17, vena cava inferior; 18, inferior mesenteric vessels; 19, spermatic vessels (Testut).

intermittently, being forced out by the contraction of the muscular tissue in the walls of the bile-ducts. Some authorities state that it flows continuously into the intestine. But whether this is so or not, the greater part is stored up in the gall-bladder during the

intervals of digestion, to be expelled therefrom during the digestive process.

When the bile leaves the liver it is a clear fluid with a specific gravity of 1010. During its stay in the gall-bladder it becomes viscid, and loses some of its water and inorganic salts, certainly some of the chlorids, which are absorbed by the gall-bladder, and its specific gravity is increased to 1030 or 1040. The viscosity in human bile is due to mucin, but that of ox's bile is due to an ingredient which was formerly thought to be mucin, but is now regarded as a nucleoproteid. That it is not mucin is shown by several facts: the nitrogen is from 14 to 16 per cent. higher than in mucin, and when boiled with a mineral acid it does not yield a reducing sugar. This substance is formed by the epithelial cells lining the gall-bladder.

FIG. 139.—Portion of gall-bladder and bile-ducts: 1, cavity of gall-bladder; 2, cavity of calyx; 3, groove separating the calyx from the bladder; 4, promontory; 5, superior valve of calyx; 6, cystic canal; 7, common bile-duct; 8, hepatic duct (Testut).

The bile is alkaline in reaction, sodium carbonate and alkaline sodium phosphate being present to the extent of about 0.2 per 1000. Its color varies: in herbivorous animals it is green; in carnivorous animals golden yellow or golden red; while in man it is of a golden yellow, though often green.

**Constituents of the Bile.**—The chemical composition of the bile varies in the same individual at different times, and this difference depends, to a considerable extent, upon the length of time

it remains in the gall-bladder. Analysis will, therefore, vary materially, according as the secretion is removed through a fistula of the bile-duct, in which case it would come directly from the liver or from the gall-bladder after having been stored there for some time.

The table on page 246 gives the results of various analyses of bile which have been made by competent chemists.

*Bile-pigments.*—These are two: *bilirubin* and *biliverdin*. Both of these are present in bile, but if the color is of a reddish brown, as in the carnivora, the bilirubin predominates, while the predominance of the biliverdin gives the greenish hue, the characteristic color of the bile of the herbivora. The formula for bilirubin is  $C_{16}H_{18}N_2O_3$ , or, as given by some writers,  $C_{32}H_{36}N_4O_6$ ; that of biliverdin,  $C_{16}H_{18}N_2O_4$  or  $C_{32}H_{36}N_4O_8$ —*i. e.*, the former passes into

Composition of Normal Human Bile.

	Bile from fistula.	Bile from gall-bladder immediately after death.	
	Copeman and Winston.	Frerichs.	Gorup-Besanez.
Water . . . . .	985.77	860.	822.7
Total solids . . . . .	14.23	140.	177.3
Sodium glycocholate . . . . .	6.28	102.2	107.09
Sodium taurocholate . . . . .			
Cholesterin . . . . .	0.99	1.6	47.3
Lecithin . . . . .		. . . . .	
Fats . . . . .		3.2	
Soaps . . . . .	1.72	26.6	22.1
Mucin, pigment, etc. . . . .			
Inorganic salts . . . . .	4.51	6.5	10.8

the latter by oxidation. It is because of a reduction in the biliverdin that the greenish color of fresh human bile becomes reddish after it has remained for some time in the gall-bladder.

In clots of blood that are old, crystals are found to which the name *hematoidin* was given by Virchow. This is identical with bilirubin. Indeed, it is now conceded that the pigments of the bile are derived from hemoglobin, the coloring-matter of the blood. Thus one of the functions of the liver-cells is to change the hemoglobin which comes from broken-down red blood-corpuscles to bile-pigment, separating from it the iron and preserving it for future blood-making.

Neither bilirubin nor biliverdin shows any absorption-bands with the spectroscope.

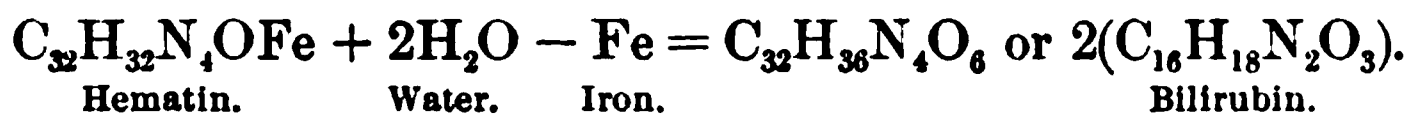
*Gmelin's Test for Bile-pigment.*—If diluted bile, or a solution containing bile-pigment, is poured into fuming nitric acid—*i. e.*, nitric acid containing nitrous acid, which is a powerful oxidizing agent—there will be produced a set of rings or zones of different colors, according to the amount of oxidation of the bilirubin. The

zone next to the acid will be the most oxidized, and will be of a yellow-red color: the product is *choletelin*,  $C_{16}H_{18}N_2O_6$ . Above this will be a zone of red or purple, becoming blue: this product is called *bilicyanin*; above all will be a green zone, *biliverdin*, which being farthest from the acid has undergone the least oxidation. This constitutes *Gmelin's reaction*, and is employed to detect the presence of bile-pigments, as in the urine. A modified form of applying this test consists in wetting a piece of filter-paper with bile, or the solution which is suspected to contain bile, and dropping the fuming nitric acid upon it, when the characteristic colors will appear.

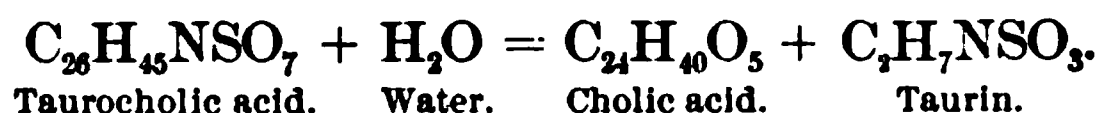
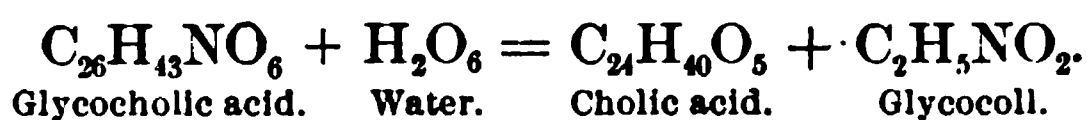
Biliary urine gives an absorption spectrum showing a wide band beginning at the red side of D and ending between D and E. Choletelin gives a band between C and F.

*Hydrobilirubin*.—This substance has the formula  $C_{32}H_{40}N_4O_7$ . It is a reduction-product of bilirubin, and is obtained by the action of nascent hydrogen, from sodium amalgam, in an alkaline solution of bilirubin. It gives an absorption spectrum, a dark band between C and F. It is with difficulty oxidized to bilirubin or biliverdin. Although bilirubin and biliverdin as constituents of the bile enter the intestine, still neither is found in the feces, but hydrobilirubin is there found, which is undoubtedly derived from the bile-pigments. This pigment of the feces has been described as *stercobilin*. A similar pigment in the urine is *urobilin*, and it is now claimed that hydrobilirubin, stercobilin, and urobilin are one and the same substance.

As already stated, it is believed that bilirubin comes from hemoglobin, the coloring-matter of the blood. In the liver this is decomposed into a proteid and hematin, the latter containing iron. The hematin takes up water, the liver-cells remove the iron, and bilirubin is formed. This may be expressed by the following equation:



*Bile-salts*.—These are *sodium glycocholate* and *sodium taurocholate*—*i. e.*, sodium united with glycocholic acid,  $C_{26}H_{43}NO_6$ , and taurocholic acid,  $C_{26}H_{45}NSO_7$ . These acids are known as *bile-acids*. Both occur in human bile, as a rule, though taurocholic acid may be absent. When glycocholic or taurocholic acid is boiled with an acid or an alkali, it takes up water and then splits up, or, as it is expressed, “undergoes hydrolytic cleavage,” into *cholic* or *cholalic acid* and an amido-acid—*i. e.*, an organic acid, one or more of whose hydrogen atoms is replaced by amidogen ( $NH_2$ ). Glycocholic acid produces *glycocoll* or *amido-acetic acid*, and cholic acid; while taurocholic acid yields *taurin* or *amido-ethylsulphonic acid*. This is represented by the following equations:



A similar decomposition of the bile-acids is believed to take place in the intestine, with the production of cholic acid.

*Pettenkofer's Test.*—When cane-sugar and strong sulphuric acid are added to bile or a solution of bile-salts a purplish or reddish-violet color is produced. This is due to the action of the sulphuric acid on the cane-sugar, producing *furfural* or *furfuraldehyd*, and this acting upon the cholic acid gives the characteristic color. In applying this test the temperature should be kept below 70° C., and not too much cane-sugar added, otherwise it will undergo carbonization. The usual way of performing this test is to add to a few drops of the fluid in a porcelain capsule a drop of strong sulphuric acid, and spread out the mixture; then add to this a drop of a 10 per cent. solution of cane-sugar. If the color does not appear, the capsule should be warmed. Inasmuch as the test depends upon the reaction between furfural and cholic acid, instead of using cane-sugar, a drop of a 1 : 1000 solution of furfural may be added to 1 c.c. of an alcoholic solution of bile-salts, and to this 1 c.c. of concentrated sulphuric acid, care being taken as before to keep down the temperature. It is said that the presence of  $\frac{1}{20}$  to  $\frac{1}{30}$  of a milligram of cholic acid may be recognized by the furfural test.

Unfortunately, Pettenkofer's reaction alone cannot be relied upon as a test for the bile-salts, inasmuch as proteids and other substances to the number of forty will give the same color. The color produced by cholic acid may, however, be distinguished from that produced by all other substances by its spectrum; two bands, one between the solar lines D and E near to E, and the other at F. The bile-acids are formed by the cells of the liver; probably from some albuminoid or proteid constituent. They are absorbed by the intestine and are not excretory products, but have various offices to perform and for which they are produced; just what these are has not been definitely determined, but it is regarded as probable that among other offices is that of dissolving the cholesterin, which would otherwise be insoluble. Other offices will be referred to in connection with the discussion of the offices of the bile as a whole.

*Cholesterin.*—The formula for this substance is  $\text{C}_{26}\text{H}_{44}\text{O}$ . It is found not only in bile, but also in nervous tissue and in the cells of plants and animals (p. 101), where it results from the katabolic processes taking place in them. It is brought to the liver by the blood, and is not formed in that organ. It is an excretory

product, and the function of the liver, so far as this substance is concerned, is to eliminate it. It undergoes no changes in the intestine, but is excreted as cholesterin in the feces.

*Lecithin.*—This is another of the constituents of the bile which, like cholesterin, is derived from nervous tissue, and whose elimination from the blood is brought about by the liver-cells.

**Offices of the Bile.**—The amount of bile which is daily secreted, being about 800 or 900 grams in the human subject, would indicate that its offices in the body must be important. It is a remarkable fact that a single anatomic element can perform so many varied functions as does the liver-cell. (1) It secretes the water of the bile; not alone, for the cells of the bile-ducts and possibly those covering the lining of the gall-bladder aid in this process. (2) It forms the bile-salts. (3) It forms the bile-pigments. (4) It separates cholesterin and lecithin from the blood. Besides these functions, all of which are related to the bile, it has others no less important in connection with the formation of glycogen and urea, both of which are discussed elsewhere.

That the passage of bile into the intestine is not essential to life, even in man, is conclusively proved by the results of the establishment of fistulæ of the gall-bladder through which all the bile that is formed is removed; indeed, under these circumstances the health is not greatly impaired.

If, however, the common bile-duct is tied, the bile which is formed is absorbed by the lymphatics, an exit from the bile-duct being due to rupture of their walls. That this absorption is not into the blood-vessels is demonstrated by detecting the bile-pigments and the bile-acids in the lymph as it is discharged from the thoracic duct into the venous system at the junction of the left internal jugular vein with the left subclavian vein; the result of this absorption is to produce jaundice.

Its most important office is probably the part which it plays in serving as the medium through which cholesterin, lecithin, and other results of katabolic metabolism are removed. Its bile-acids are to a certain extent absorbed from the intestines and serve as carriers of cholesterin. Its pigments are to a certain extent also absorbed from the intestine, though what advantage results therefrom is not known. Its amylolytic action, if it possesses any, is exceedingly slight, and it has no proteolytic power. It aids the steapsin of the pancreatic juice in splitting up fat into its fatty acids and glycerin, and it furnishes, as we have seen, alkaline salts to unite with fatty acids in the small intestine and form soaps, thereby assisting materially in the emulsification of the fats which are not split up.

The bile aids also, probably by virtue of the bile-salts, in the absorption of fats. The theory that the bile-acids dissolve the fat and that the intestinal walls moistened thereby absorb the fat more

readily because the contact of fat and membrane is closer than it otherwise would be, is abandoned. This theory was based on the reputed facts that oil would rise higher in a capillary tube which had been moistened with bile than in one which had been moistened with water, and that a filtering medium wet with bile would permit oil to pass through more readily than one wet with water. Experiment, however, demonstrates that these are not facts. In view of the present belief that absorption depends not upon osmosis, but upon the activity of lining epithelium, it is not improbable that the cells covering the mucous membrane of the intestine are stimulated by the bile-acids to increased absorption of fat.

The antiseptic property of bile is very small; still, when bile is not permitted to enter the intestine putrefaction of the intestinal contents takes place more readily than is normal. The explanation of this is not satisfactory.

Another purpose which bile subserves is to precipitate the proteids of the chyme which are not peptonized, or only partially so, as, for instance, syntonin, as that mixture comes into the intestine from the stomach. With this precipitated matter is also some mucin from the bile. The result of this precipitation is a tenacious mass which adheres to the intestinal wall, and which is therefore longer exposed to the action of the digestive fluids of the intestine, and, therefore, more perfectly digested than it otherwise would be.

**Innervation.**—So far as the formation of bile is concerned, the liver-cells do not appear to be supplied with secretory nerves. There is great difficulty in determining this question with certainty, for the reason that in stimulating the nerves to the liver vasomotor fibers are stimulated, and this, of course, affects the blood-supply to the organ, so that it is impossible to say whether what occurs is the result of stimulating secretory nerves or of an increased supply of blood. There is no doubt, however, that it is to the blood of the portal vein that the secretion of bile must be ascribed, and that when this supply is increased the bile secretion will be correspondingly augmented. This occurs during digestion, and it is, therefore, at this time that the amount of bile is increased.

It is probable that the muscular tissue of the gall-bladder and bile-ducts is supplied with nerves, so that when the mucous membrane of the stomach or intestine is stimulated afferent impulses reach a nerve-center through the vagus, and efferent impulses pass out and are carried to this muscular tissue through the splanchnics; the action is, in other words, reflex.

**Movements of the Small Intestine.**—When the food enters the small intestine through the relaxed sphincter pylori, the free hydrochloric acid present brings about, by contact with the duodenal mucous membrane through reflex action, a closure of the pyloric sphincter, and thus the quantity of food material



passed into the intestine is limited and the power of the intestine not overtaxed. Later, the acidity is neutralized by the bile and pancreatic juice, and the free acid in the stomach causes a relaxation of the sphincter and another portion of the stomach-contents enters the small intestine. Cannon states that the manner in which the food is mixed with the digestive secretions, exposed to the absorbing wall, and carried forward in the small intestine is considerably different from the process observed in the large intestine and in the stomach. To the admirable process by which these functions are performed in the small intestine he has given the name "rhythmic segmentation." This activity of the muscular wall is first seen in the duodenum when a mass of food has accumulated there after repeated relaxations of the pylorus. The mass of food is observed at first to be wholly quiet. Suddenly irregular movements take place about it, and then at regular intervals along its length constrictions of the circular musculature separate the mass into a number of segments of equal size. Hardly have the constrictions thus taken place when similar constrictions begin to appear about the middle of each segment. As these new constrictions deepen, the first constrictions begin to relax. Finally, when the new constrictions have completely divided the segments, the first constrictions have entirely relaxed and the neighboring halves of the divided segments unite to form new segments in the region of the first constriction. Now these new segments are again divided by circular constrictions about their middle, and neighboring halves of these divided segments unite to make a third series, and so on. This process of rhythmic segmentation of the food may go on for several minutes in the duodenum (at the rate of thirty divisions per minute in the cat), so that the food, coming from the stomach, becomes thoroughly mixed with the out-pouring secretions of the liver and the pancreas. It is usual for the process to be brought to an abrupt end in the duodenum by active peristalsis. A peristaltic wave forms behind the mass of food and sweeps it swiftly forward through several coils of the intestine.

The movements of the small intestine, like those of the stomach (p. 208) and large intestine, are inhibited whenever the animal experimented upon manifests signs of anxiety, rage, or distress.

#### DIGESTION IN THE LARGE INTESTINE.

Undoubtedly, the process of intestinal digestion, which is mainly carried on in the small intestine, is continued to some extent in the large intestine, as the conditions there existing are favorable to a continuance of this process, but the enzymes, which are the efficient agents, are those of the fluids which have come with the food into the large intestine, the mucous membrane here producing no enzymes with digestive powers. In studying the process of absorption we shall see that, although the large intes-



tine possesses no digestive power, it has considerable power of absorption.

**Movements of the Large Intestine.**—In the cecum, ascending and transverse colon, the normal activity, according to Cannon, is an antiperistalsis. Constriction waves start in the transverse colon and pass backward toward the cecum. These waves, unlike those of the stomach, do not run in continuous rhythm; they occur usually in periods lasting about five minutes, and recur every fifteen or thirty minutes. He says: "The antiperistalsis in this part of the large intestine seems, indeed, to give a reason for the presence of a valvular structure at the entrance of the small intestine into the large. Hundreds of antiperistaltic waves have been seen coursing toward the cecum, and only twice has food been observed to be pressed back into the ileum through the ileocolic valve. Inasmuch as the valve is competent for the food which has gone from the small into the large intestine, the antiperistaltic waves have the same effect here as the peristaltic waves have in the stomach when the pylorus remains closed. For, when a constriction occurs, some of the mucous surface of the colon becomes enclosed by the narrowed muscular ring; and, as this constriction passes on, fresh areas of this surface are continually pressed inward around the narrow orifice, while a thin stream of food is passing in the opposite direction. As waves recur about five times a minute, twenty-five waves or more affect every particle of food in the cecum and in the ascending colon in this churning manner during each normal period of antiperistalsis. The result must be again a thorough mixing of the contents with the digestive secretions brought from the small intestine and an exposure of the digested food to the absorbing wall.

"Immediately after food passes from the ileum into the large intestine a strong tonic contraction of the cecum and the ascending colon is commonly observed, which serves to press onward toward the rectum the contents of these parts. Antiperistaltic waves follow at once the general contraction, so that much of the food which has been pressed onward is returned into the cecum. With the repetition of this process, however, more and more material appears at the end of the transverse colon, and on its appearance there a persistent ring of contraction cuts it off from the region of antiperistalsis; as still more food appears in the large intestine this ring moves slowly onward toward the rectum, pressing a mass before it, and is followed by other similar rings carrying onward similar masses by very slow peristalsis.

"Thus, in the large intestine the function of mixing the food with the digestive secretions and of exposing this food to the absorbing walls is performed by an antiperistalsis at the beginning of the large intestine. It is here that the last valuable constituents of the food are worked over and taken into the body. The remnant of unused material is propelled onward by occasional strong contrac-

tions of the whole region of antiperistalsis. These contractions squeeze the material toward the end of the transverse colon where slowly-moving peristaltic waves force it to the rectum."

These movements, as in the case with the stomach and small intestine, are inhibited by rage, anxiety, or distress.

### BACTERIAL DIGESTION.

Bacteria are found in considerable numbers in the mouth, stomach, and intestine; more than sixty species are recorded by Sternberg as having been found in the mouth; and seventy-four have been isolated from feces and the intestines of cadavers. Those which occur in the stomach consist of mouth-bacteria which have been swallowed together with bacteria which are in the food and drink. We have already referred to some of the pathogenic or disease-producing bacteria, and the effect of hydrochloric acid upon them (p. 196). But besides these there are others which have a true digestive action on the food-stuffs. Inasmuch as there is no free hydrochloric acid in the stomach for about half an hour after food has entered it, the antiseptic action of this acid is not exerted for that length of time, and the conditions are favorable for bacterial action. During this time some of the carbohydrates may be decomposed, with the result of producing lactic and other acids and setting free hydrogen gas. Proteids do not, however, appear to be acted upon by bacteria in the stomach. In the small intestine there is some decomposition of proteids, but not to any considerable extent. Lactic and other organic acids are, however, produced from carbohydrates. These changes in both proteids and carbohydrates are due to the action of bacteria.

The action of the intestinal bacteria upon proteids has been likened to that of trypsin. The proteid is dissolved, and then changed into albumoses and peptones. A part goes on to the stage of tyrosin, which becomes still further decomposed into paraoxyphenylpropionic acid, paraoxyphenylacetic acid, phenol, and parakresol. From another portion of the proteid are formed indol, skatol, and skatolcarbonic acid. These substances are not derived from tyrosin nor, indeed, from peptones, but from some unknown intermediate substance derived from the proteid itself.

All of the carbohydrates of the food seem to be subject to bacterial action. Thus starch and even cellulose may be decomposed by the appropriate bacteria. As results of carbohydrate decomposition are produced ethyl alcohol, lactic, butyric, and succinic acids, together with carbon dioxid and hydrogen.

The fats are normally unchanged by bacterial action; in the absence of bile or pancreatic juice they are decomposed, with the formation of fatty acids.

It is claimed that one important office performed by the intestinal bacteria is to prevent putrefaction.

From all the facts known in connection with bacteria, the conclusion is inevitable that they serve a useful purpose in the economy; they may, however, when in excess, produce such amounts of harmful substances as to be injurious when these are absorbed.

### ABSORPTION OF THE FOOD.

Attention has already been called to the fact that a large part of the food-stuffs taken into the body are not in a condition to be absorbed by the blood, nor to be utilized by the tissues when brought to them by that fluid (p. 167), and that digestion consists in bringing about the changes in them necessary to effect this result. It is these changes which we have studied, and which will prepare us to understand the process of absorption.

Manifestly, absorption might take place anywhere in the alimentary tract from the mouth to the anus, but it has been demonstrated that in some portions of this canal very little absorption, if any, takes place, and that in others the greater part of the process is carried on.

**Mouth-absorption.**—Under ordinary circumstances there is no absorption while substances are in the buccal cavity. This is certainly true for the food-stuffs, though that it may occur for some other substances is proved by the fact that cyanid of potassium taken into the mouth and retained there will produce death.

There is likewise no absorption while food is passing through the esophagus; the time occupied in the transit is altogether too brief, and the conditions generally are unfavorable.

**Gastric Absorption.**—The food-stuffs which enter the stomach are: (1) inorganic, water and salts; (2) carbohydrates, starch and sugars; (3) fats or oils; and (4) proteids.

**Inorganic Food-stuffs.**—Water taken into the stomach by itself is not absorbed to any extent by that organ. Von Mering demonstrated this in a dog in which he first established a fistula in the duodenum, and then gave it by the mouth 500 c.c. of water. Almost as soon as it reached the stomach it was forced out by contraction of the muscular coat into the duodenum in spirits, and in twenty-five minutes 495 c.c. passed out through the fistulous opening in the intestine. When water contains in solution substances which are absorbed by the stomach-walls, some of the water is also absorbed with them.

The evidence as to the absorption of salts is very incomplete. Sodium iodid in 3 per cent. solution is absorbed, but to a slight extent if the solution is more dilute. Many substances, such as mustard or alcohol, hasten its absorption, probably by stimulating the epithelium.

**Carbohydrates.**—Starch is not absorbed as such, but must be changed into maltose, which process, as we have seen, does take

place to no inconsiderable extent in the stomach ; although it also is carried on more energetically in the small intestine. All varieties of sugar—dextrose, lactose, saccharose, and maltose—are absorbed in the stomach, and this is also true of dextrin. Some of the saccharose is inverted to dextrose and levulose in the stomach, and doubtless absorbed in this form to some extent, while the rest of it undergoes the same change in the small intestine. It is essential, however, that the solution should be concentrated ; at least this is true of dextrose, of which very little is absorbed until the concentration equals 5 per cent., and the rate of absorption increases up to a concentration of 20 per cent. Alcohol causes increased absorption of sugar, as it does of sodium iodid, and doubtless for the same reason. Taken as a whole, the amount of the sugars absorbed from the stomach is probably not great.

**Peptones.**—These are also absorbed from the stomach, though, as in the case of dextrose, only when the concentration reaches 5 per cent., so that the absorption of peptones from the stomach is relatively small.

**Fats and Oils.**—With the exception of the physical change, due to the temperature of the stomach, by which the fats and oils are rendered more fluid, and their probable splitting up into fatty acids (p. 199), no change takes place in them, nor are they absorbed to any extent whatever.

**Alcohol.**—The fact that alcohol is readily absorbed from the stomach has been sufficiently dwelt upon (p. 161).

From the above considerations it will be seen that gastric absorption is not a process of much importance ; indeed, the cases of the entire removal of this organ, to which we have referred, demonstrate that the exercise of what little absorptive power it possesses, is unnecessary. We desire to direct special attention to the fact that sodium iodid, dextrose, and peptones are more readily absorbed when alcohol is also present. This emphasizes the view now held as to absorption,—that it is not a mere matter of osmosis, but is due to an actual selective power of the epithelial cells, and that this is more actively exercised under the stimulating action of alcohol or other substances having like power.

**Absorption by the Small Intestine.**—It is from the cavity of the small intestine that the greater part of absorption takes place, the products of digestion passing into the villi, a part entering the capillary blood-vessels and reaching the liver through the portal vein ; while another part enters the lacteals, and passes on into the thoracic duct, from which it is discharged into the blood-vascular circulation. While osmosis is doubtless one of the factors in this process, still the selective power of living cells is much more potent.

The materials to be absorbed are: (1) water, salts; (2) carbohydrates; (3) fats; (4) proteids.

**Absorption of Water.**—As was stated in connection with gastric absorption (p. 254), water is not absorbed to any extent from that organ, most of that taken in being passed on into the small intestine. Experiments have shown that the water which enters the small intestine is absorbed by the capillaries of the villi; and yet even when large quantities are absorbed, an analysis of the blood shows no change, as might be expected, the excess being eliminated by the kidneys.

**Absorption of Carbohydrates.**—The dextrose and levulose, formed by the action of the enzymes, are absorbed by the veins and carried by the portal vein to the liver, but there is evidence that saccharose, and even dextrin and starch, can be taken up by the cells; although, as we have seen, the action of the intestinal enzymes is very powerful, and doubtless the amount of carbohydrates remaining in any other condition than that of dextrose or levulose is very small. But, even if carbohydrates should be absorbed in any form but these, they would be inverted while passing through the cells. It is a remarkable fact that lactose, which forms so important a part of the milk, the sole food of the growing child, is unaffected by the enzymes; however, in its passage through the epithelial cells it is inverted, the product being probably dextrose and galactose. Maltose, also, may be inverted by the columnar epithelium.

It is, then, mostly in the form of dextrose and levulose that the carbohydrates of the food enter the blood and are carried to the liver, and from these glycogen is formed. Saccharose and maltose cannot be thus changed by the liver-cells. It sometimes happens that very large quantities of sugar are taken in with the food; if the amount is so great that the liver and muscles cannot convert it all into glycogen, the overplus is eliminated by the kidney, and appears in the urine, constituting *alimentary glycosuria*.

**Glycogenic Function of the Liver.**—As we have seen, the result of the digestion of starch is its conversion into maltose, or maltose and dextrin, which later becomes dextrose, in which form, for the most part, the carbohydrates of the food reach the liver. Some levulose may accompany it to the liver, where, according to some authorities, it becomes dextrose. If during the time of the absorption of sugar the blood going to the liver through the portal vein and that coming from it by the hepatic vein are analyzed, it will be found that the former contains much more sugar than the latter; from this fact the inference is inevitable that some change takes place in the sugar during its passage through the liver. This change consists in its conversion by the hepatic cells into glycogen, which is a process of dehydration, the reverse of what takes place when the starch or glycogen of the food is converted into sugar.

**Formation of Glycogen from Carbohydrates.**—The liver weighs between 1500 and 1900 grams, and as the amount of glycogen in this organ may reach 10 per cent. of its weight, 150 to 190 grams, it is manifest that the carbohydrates of a single meal, which would ordinarily amount to about 100 or 150 grams, could be stored as glycogen in the liver, provided that before the next meal this was all reconverted into liver-sugar, and as such passed out into the blood, leaving the liver free from glycogen; but this does not occur, so that we may conclude that all the carbohydrates are not deposited in the liver. As has been stated (p. 62), the muscles contain glycogen, sometimes to the amount of 1 per cent., and this undoubtedly comes from the carbohydrates of the food. If, however, all the glycogen in the liver and the muscles is taken into account, together with the dextrose in the blood, about 0.12 per cent., there still remains an overplus unaccounted for, and this is believed to enter into the formation of proteids and other substances; indeed, it is not by any means certain but that some of the absorbed dextrose may exist in the blood as dextrose and never undergo conversion into glycogen, but perform the same office as the dextrose which does result from liver or muscle glycogen—*i. e.*, serve as a source of energy.

**Formation of Glycogen from Proteids.**—It has been abundantly demonstrated that feeding animals on proteids alone, without any admixture with carbohydrates, results in the formation of glycogen in both liver and muscles. It follows from this that there exists in the body the power of decomposing proteids, and from the carbon, hydrogen, and oxygen which enter into their composition to form glycogen. By this statement it is not intended to convey the idea that the proteid is broken up into its chemical elements, but rather that it is decomposed into a non-nitrogenous and a nitrogenous portion; the non-nitrogenous portion becoming ultimately glycogen, possibly passing through a preliminary stage of dextrose, some of which may remain as dextrose, and not undergo conversion into glycogen.

**Formation of Glycogen from Fats.**—It is generally accepted that no glycogen is formed from fat. There are authorities, however, who hold the contrary opinion, basing this upon certain experiments, and upon the fact that in germinating seeds such a change does take place. It may be regarded as an unsettled question.

It is an interesting fact that liver-glycogen is increased upon the administration of glycerin. While glycerin is not convertible into glycogen, it seems to prevent the change of the glycogen in the liver into dextrose, and hence causes its retention, which has the same effect upon the total amount in the liver as if more had been formed.

**Glycogenic Theory.**—The carbohydrates serve as sources of energy—*i. e.*, they are oxidized to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  in the body,



and heat and work are the result of this oxidation. The various stages through which they pass are not all known, but as to some there seems little doubt. Thus the formation of dextrose and levulose, during digestion and absorption, and the deposition of the greater part of these in the liver and muscles as glycogen, are generally accepted; but as to what changes take place in the glycogen there is a difference of opinion.

**Theory of Claude Bernard.**—The opinion advanced by this distinguished physiologist, who, in the year 1848, discovered that sugar was formed in the liver, and in 1857 that it had its origin in glycogen, was that the dehydration of the dextrose by the liver-cells, by which glycogen is deposited in that organ, is a provision for the storage of the carbohydrates of the food; otherwise the dextrose, after it had reached a percentage above that which normally exists in the blood, 0.1 to 0.2 per cent., would be of no use to the body, inasmuch as it would be eliminated by the kidneys. But, being stored up in the liver at the time of its absorption, it is, in the intervals of digestion, gradually converted into dextrose, which passes out in the blood of the hepatic veins and serves the body as a source of energy. It is a matter which is still in doubt whether this conversion is a zymolytic action—*i. e.*, whether it is produced by an enzyme or by the liver-cells as one of their peculiar functions. The argument against the change being due to an enzyme is, that while amylolytic enzymes have been found in the liver, which change glycogen to maltose, here is a change to dextrose; but, on the other hand, a ferment has been obtained from the liver which does convert glycogen into dextrose, so that this argument has but little weight. That the power to change glycogen into dextrose resides in tissues independently of the presence of enzymes is shown by the fact that the muscles of the body, during the entire life of an individual, and other organs, such as the placenta, during fetal life, have the same power as the liver to form glycogen from the dextrose of the blood. While Bernard's theory has been generally accepted by physiologists, there are those who oppose it, and among these the most prominent is Pavy.

**Theory of Pavy.**—Pavy regards the dextrose which Bernard and others have found in the hepatic vein as due to a change brought about by the action upon the glycogen of an enzyme formed in the liver after death. His analyses of the blood of the ascending vena cava, which carries the blood coming from the liver, show no increase of sugar over the blood obtained from other portions of the circulation, provided that it is examined before post-mortem changes have set in. For this purpose he kills the animal by a blow upon the head, and immediately withdraws the blood. According to this theory, during life the glycogen of the liver does not become converted into dextrose, but is a source of fat and of proteid. That fat is formed in the body in considerable amount

on a carbohydrate diet is a well-known fact, and one of the restrictions placed upon obese individuals who are endeavoring to reduce their fat is to abstain from sugar as much as possible. The glycogen of the muscles may also serve for the purpose of fat formation. That glycogen serves also as a source of energy there is no doubt.

It may seem to the student a strange fact that what appears so simple a matter to determine as this which is in dispute between the adherents of the two theories referred to cannot be definitely settled; but it is to be borne in mind that the blood is a very complex fluid, and the methods for detecting with certainty the amount of sugar in the blood are not sufficiently exact to warrant a positive statement, for in this fluid there are other reducing substances than sugar. Then, too, it must be remembered that the entire blood of the body passes through the liver every two minutes, so that while the total amount of sugar passed out from that organ in twenty-four hours might be considerable, yet the difference in amount found at any given moment in the blood of the hepatic vein, over and above that found in other parts of the circulation, would be so small as not to be within the possibility of determination. In view of the conflicting evidence we must, therefore, acknowledge that the question is still an open one, with the weight of evidence at the present time in favor of the theory of Bernard.

**Diabetes.**—This is “an affection characterized by an immoderate and morbid flow of urine.” When there is no sugar in such urine the condition is called *diabetes insipidus*; but when the urine contains an abnormal amount of sugar, *diabetes mellitus*, or simply *diabetes*. The term *glycosuria* refers to the excessive amount of sugar in the urine, and this condition may exist, temporarily, in other affections than diabetes. The form in which the sugar exists is principally that of dextrose, though there is doubtless some maltose also present. The source of this sugar may be from glycogen or from proteids. If from the former, it may be caused by excessive conversion of glycogen into dextrose (Bernard), or from a failure on the part of the liver to convert into glycogen as much of the absorbed sugar as occurs normally (Pavy). Whichever view is taken, the treatment consists, among other things, in depriving the patient of all foods which make sugar. In some cases, however, even after this is done, the glycosuria continues, and the only possible explanation is that the sugar is produced from proteids.

**Artificial Diabetes.**—The condition of glycosuria may be artificially produced:

(1) *Puncture-diabetes.*—Puncture in the floor of the fourth ventricle of the brain, the region in which is situated the vasomotor center, will cause glycosuria. This center is stimulated by the puncture, the arterioles of the liver are constricted, thus



reducing the amount of arterial blood in that organ, which results in an increased activity of the liver-cells, thereby causing an excessive conversion of glycogen into sugar. This is one explanation which has been given to account for the phenomenon. Another is that the glycosuria is due to a direct action upon the secretory nerves of the liver.

(2) *Phlorizin-diabetes*.—Glycosuria may also be produced by the administration of a number of different substances; among these are phosphoric and lactic acids, strychnin, arsenic, phosphorus, and especially phloridzin or phlorizin, a bitter substance, having the chemical formula  $C_{21}H_{24}O_{10}$ , obtained from the bark of the root of the apple-, pear-, and cherry-tree. Phlorizin is a glucosid. A glucosid is a vegetable principle which, when treated with acids and some other substances, yields glucose and another substance which is characteristic of the particular plant from which the glucosid was obtained. There are many glucosids which have been isolated; among these are, amygdalin, from bitter almonds; digitalin, from digitalis; esculin, from the horse-chestnut, etc. It was thought at one time that the glycosuria which follows the administration of phlorizin was due to the glucose which it contains, but it is now known that phloretin, which is a crystalline substance formed by the action of an acid on phlorizin, and which contains no glucose, will have the same effect as the phlorizin itself.

(3) A diabetic condition may also be produced by removing the pancreas. Of this form of glycosuria we have already spoken (p. 239).

**Absorption of Proteids.**—The theory that the digestion of proteids consists in their being changed into a more diffusible form, and that in this condition they are absorbed by the physical process of osmosis, has been to a considerable degree abandoned. For while it is true that proteoses and peptones are diffusible, while native albumins are not, still it has been shown that egg-albumin is absorbed as such, although it is non-diffusible. This absorption takes place in both the small and large intestine; in the former, under circumstances which demonstrate that it could not have been previously peptonized, and in the latter, of course, there is no peptonizing enzyme. We must, therefore, attribute the absorption of proteids to the epithelial cells, to whose efficiency in the process of absorption we have so frequently had occasion to refer. Not only is egg-albumin absorbed, but the same is true of syntonin as well. There is this difference, however, that when egg-albumin is absorbed in such quantity that it cannot be changed into an assimilable form while passing through the cells of the villi, it is carried by the blood to the kidneys, where it is eliminated, producing an "alimentary albuminuria," while syntonin is utilized by the tissues. There is little doubt that it is in the form of proteoses and peptones

that the proteids are absorbed, and that the capillary blood-vessels of the villi are the efficient agents in this process. Some recent experimenters, Asher and Barbèra, claim that some proteid is absorbed by the lacteals, but Mendel conducted an investigation as a result of which he concludes that "under ordinary circumstances by far the greater share in the process must still be delegated to the capillaries of the villi."

Although proteids are mainly absorbed as proteoses and peptones, yet during this act they lose their identity. In other words, while passing through the epithelial cells which cover the villi they are so changed that neither proteose nor peptone can be found in the blood, and if these substances are directly injected into the blood they are eliminated by the kidneys and are found in the urine. Indeed, if the amount is sufficient they act as poisons, causing insensibility, lowering blood-pressure, diminishing or destroying the coagulability of the blood, and producing death. Although the power to convert proteoses and peptones into a form which can be assimilated is claimed for the leukocytes present in the intestinal wall, the evidence seems conclusive that this claim is without substantial foundation, and that it is to the columnar epithelial cells covering the villi that the change is to be attributed. Up to the present time the form of proteid into which these substances are changed has not been determined, though it is doubtless a coagulable proteid, and probably serum-albumin or globulin.

**Absorption of Vegetable and Animal Proteids.**—The products of vegetable proteolysis are not so completely absorbed as are those of animal origin. It is stated by Moore that this is in part due to their envelopes of indigestible cellulose, in part to their shorter stay in the intestine because of their action in causing increased peristalsis, and in part to their less digestible character. He further states that the proteids of some leguminous plants and cereals are absorbed nearly as perfectly as those of animal origin, while in most others (potato, lentil) it is much less complete (22 to 48 per cent. less). The percentage of the nitrogen of meat or egg appearing again in the feces in man amounts to but 2.5 to 2.8 per cent.; that of milk, to but 6 to 12 per cent.

**Absorption of Fat.**—There is no dispute as to the lacteals being the channels through which the fat reaches the blood-vascular circulation by way of the thoracic duct; the presence of fat in the vessels has been observed too often to admit of any doubt on this point. Indeed, it is the milky appearance given by the fat-particles to the contents of these vessels which has given to them the name of lacteals (Fig. 120), but as to the manner and form in which fat passes into the villus to reach the lacteals two theories are held: (1) the emulsion theory and (2) the solution theory, or, more correctly, solution theories.

**Emulsion Theory.**—This theory is the older, and explains the

absorption of fat by supposing that the greater part of it is emulsified by the action of the pancreatic juice, and, being thus broken up into a state of extremely minute subdivision, the particles pass into the villi, reach the lacteals, and by way of the thoracic duct enter the blood-vascular circulation. In this theory the splitting up of the fat plays the important part of aiding in the emulsifying process (p. 101). Although fat-particles have often been observed in the interior of the epithelial cells, they have never been seen in the striated borders of these cells, which is a remarkable fact if as fat they pass through these borders to reach the interior. Nor is there any special reason why fat should be taken up by the columnar epithelium more than any of the products of digestion. It has been supposed that the lymph-corpuscles, already described as existing between the epithelial cells of the villi, put out pseudopodia and take in the fat-particles, passing them on through the reticular tissue of the villi (p. 223); but, as already stated, it is in the columnar epithelial cells that the fat is seen during the

a                      b      c      d

FIG. 140.—Longitudinal section through summit of villus from human small intestine;  $\times 900$  (Flemming's solution): at *a* is the tissue of the villus axis; *b*, epithelial cells; *c*, goblet-cell; *d*, cuticular zone (Böhm and Davidoff).

time of its absorption, and these are entirely distinct from the lymph-corpuscles.

**Solution Theories.**—Of these there are two: (1) the soap theory and (2) the fatty-acid theory.

**Soap Theory.**—This theory takes cognizance of the fact that soaps are formed in the small intestine by the action of steapsin on the neutral fats, by which they are split up into fatty acids and glycerin, the fatty acids uniting with some of the alkali of the intestinal fluids with the result of forming soluble alkaline soaps. The theory under consideration supposes that these soaps, together with the glycerin, are absorbed by the columnar epithelium, and that when within the protoplasm the acids and glycerin again unite by virtue of cell-action to form neutral fat, which is seen in the interior of the cells. We have already referred to the fact that pancreatic juice has the power of decomposing all the fat of an ordinary meal into fatty acids and glycerin during the time that it remains in the small intestine. The objection to the soap theory, that there is not enough alkali in the body to combine with the fatty acids which would result from the decomposition of the fat which is taken in as food, is met by the explanation that only a small amount is needed at a given time to form a soap, and that as soon as the soap has entered the cells it is again decomposed into fatty acids and alkali, the latter returning to the blood and being again available for use, while the acids unite with the glycerin to form neutral fat.

**Fatty Acid Theory.**—The other theory is that fatty acids, formed in the manner stated, are dissolved by the bile, and in this form are absorbed, the fatty acids uniting with the glycerin which was absorbed at the same time and forming neutral fat. There is evidence showing that when fatty acids alone are absorbed, glycerin is formed, probably by the columnar epithelium, and that by the union of the two neutral fat is produced.

The evidence seems conclusive that fats are absorbed as soaps and fatty acids, and not as emulsified fat, the fatty acids being dissolved by the bile, the salts and pseudomucin of which are the efficient factors in causing this solution.

In summing up this portion of the section on the "Chemistry of the Digestive Processes," in Schäfer's *Text-Book of Physiology*, Moore says: "It is probable, then, that in all animals a great part of the fat is absorbed and dissolved in the form of soaps; but in some animals a part is also absorbed as dissolved fatty acids, while in others the entire quantity leaves the intestine in the form of soaps."

**Course of Fat from Columnar Epithelium to the Lacteals.**—Although fat is not absorbed as an emulsion, it is in this form that it exists in the interior of the epithelial cells after its re-formation from the fatty acids and glycerin. We have already referred to the large number of lymph-corpuscles, or leukocytes, in the tissues composing the villi. During the absorption of fat these cells contain fat, and they doubtless carry this to the lacteals, there

either depositing it while still maintaining their integrity, or setting it free by themselves breaking up and disintegrating. Some authorities hold the opinion that the contractions of the protoplasm of the columnar epithelial cells forces out the fat, and that the particles pass through the spaces between the cells and thus reach the lacteals.

**Final Disposition of the Absorbed Fat.**—Inasmuch as no more than 60 per cent. of the fat absorbed finds its way into the thoracic duct, it might be inferred that the lacteals were not the only channels of absorption, and that the capillary blood-vessels of the villi had a part in this process, but there is no more fat found in the blood of the portal vein during the period of fat absorption than in the blood of the rest of the body, and even this is not increased if the contents of the thoracic duct are not permitted to enter the venous circulation. Just what becomes of the 40 per cent. unaccounted for is not known. It was long regarded as impossible for the absorbed fat to be deposited in the tissues unaltered, and it was supposed that it all underwent such changes as to destroy its integrity, and that the fat which existed in adipose tissue and elsewhere was entirely a new formation. In reference to this Liebig said: "In hay or the other fodder of oxen no beef-suet exists, and no hog's lard can be found in the potato-refuse given to swine." While it is true that some of the fat of the body is produced from other substances than the absorbed fat, still, the evidence is conclusive that under certain circumstances this is deposited in the tissues without undergoing any change whatsoever. If a dog is starved until the reserve supply of fat has been exhausted, and it is then fed with rape-seed or linseed oil or mutton tallow, fat will be again deposited in the tissues and in it some of the fat given as food will be recognizable. It is, however, a question whether this occurs except under the exceptional conditions here mentioned, although some of the best authorities state that the fat in the blood after a meal is eventually stored up in the connective-tissue cells of adipose tissue. Others claim that the fat of the food is completely oxidized, and that the body-fat is formed from proteids or carbohydrates, or both. The probabilities are that proteids and carbohydrates are the principal sources of the body-fat, and that fat itself is sometimes a contributory factor, although its main office is to supply the body with heat or other form of energy.

**Absorption by the Large Intestine.**—Although destitute of digestive power, this portion of the alimentary canal plays an important part in the process of absorption. The food undergoes digestion in the stomach and small intestine, staying in the former from one and a half to five hours, and in the latter also a variable time. In one case, in which by reason of the existence of a fistula at the end of the small intestine it was possible to investigate this question, it was found that food began to enter the large intestine from

two to five and a quarter hours after it had been eaten, and that the last portions did not reach the fistulous opening until from nine to twenty-three hours after its ingestion. It would appear that in this case the duration of gastric and intestinal digestion must have been very brief—much briefer than in most individuals.

That water is absorbed by the walls of the large intestine is conclusively shown by the fact that the contents of the small intestine when they pass into the large are quite liquid, but are ordinarily relatively solid when they reach the lower part of this portion of the intestine. If the duration of the stay of the contents of the large intestine is, as stated, twelve hours, the time is certainly sufficient for important changes. There are, however, no enzymes formed by the glands of the mucous membrane, but the evidence is overwhelming that proteids are here readily absorbed. This power possessed by the large intestine is made use of in certain diseases of the stomach, in which diseases that organ is unable to perform its function, when by means of nutrient enemata, skilfully administered, life may be maintained for a long time. In a case of circumscribed peritonitis from perforated gastric ulcer a female patient was nourished on the following rectal enema for ninety-four days, during which time she lost but 2700 grams in weight :

Lean beef . . . . .	300 grams ;
Pancreas . . . . .	150 “

These were well rubbed up in a mortar and strained, and then there were added :

Water . . . . .	q. s. ;
Carbonate of sodium . . . . .	5 grams ;
Fresh ox-gall . . . . .	25 “

This sufficed for four enemata a day when diluted with a sufficient amount of tepid water.

There is evidence that sugar and fats can also be absorbed from the large intestine.

## FECES AND DEFECATION.

The term feces is applied to the contents of the large intestine after all that is nutritious has been absorbed. As these pass along this portion of the alimentary canal they become more and more consistent by reason of the absorption of the water until, having been reduced to a mass of varying consistency, they are expelled from the rectum in the act of *defecation*.

**Quantity of Feces.**—The amount of feces daily passed by



a male adult varies from 120 to 150 grams; this may be increased to 500 grams, if the diet is a vegetable one. About 74 per cent. of feces is water.

**Color of Feces.**—The color of feces is very much affected by substances ingested. Normally it may be called brown, due to bile-coloring matter, or to hematin derived from the blood-coloring matter hemoglobin, which occurs in meat, or to both. Large quantities of bread and fat give to the feces a yellowish color.

**Reaction of Feces.**—The statements on this point are at variance, and indeed the reaction is not always the same. One authority states it to be alkaline on the surface, due to contact with the mucous membrane of the intestine, and acid in the interior; another regards the feces as having an alkaline reaction ordinarily, and as being acid exceptionally. In infants they are said to be acid.

**Composition of Feces.**—The feces contain such portions of the food as are indigestible, as cellulose, keratin, and chlorophyl, and will therefore vary in composition according to the composition of the food. In addition there enter into its composition various substances derived from the bile: *stercobilin*, which represents all that remains of the bile-pigments, and which is the same as urobilin, and hydrobilirubin; *cholesterin*, *excretin*, *excreteic acid*, *indol*, *skatol*, to the last of which substances the fecal odor is principally due; volatile fatty acids, calcium or magnesium soaps, mucin, ammonia, sulphuretted hydrogen, carbon dioxid, hydrogen, nitrogen, methan, and numbers of bacteria (Fig. 141). These gases are the result of the decomposition of the proteids by the action of bile. Besides these, the feces may contain the products of the excretory action of the epithelium of the gastro-intestinal canal (p. 208).

**Meconium.**—The first feces which are evacuated by the infant at birth are termed *meconium*. This is dark brownish green in color, acid in reaction, and contains mucin, biliverdin, bilirubin, bile-acids, cholesterin, fats, fatty acids, and the phosphates and sulphates of calcium and magnesium.

**Defecation.**—The act of defecation is governed by the anospinal center. The mucous membrane and muscular coat of the rectum are supplied with nerves from the several plexuses of spinal nerves. Feces do not ordinarily pass into the rectum until about the time of evacuation, when they are expelled from the sigmoid flexure into the rectum. At this time the sphincter ani is in a state of contraction, which is its usual condition, kept so by the impulses that come from the spinal cord. This contraction keeps the anus closed even during sleep, and is entirely independent of the action of the brain; it is an involuntary act. When, however, feces enter the rectum, the nerves of its mucous membrane become stimulated, and impulses are conveyed by afferent nerves to the anospinal center in the lumbar enlargement

of the cord, and from this impulses are reflected which, conveyed to the sphincter, cause its relaxation. Under the influence of similar impulses which pass to the levator ani this muscle contracts and draws upward the edges of the anus, causing it to open, while at the same time the muscular fibers of the rectum contract and expel the feces. If the stimulation is very pronounced, the abdominal muscles may also be called into action irrespective of the will, but when the stimulus is slight they may only respond when called upon by the brain. The connection between the brain and the anospinal center is very close, so that the action of the latter may for a time be inhibited; but if the rectum becomes very much distended, the impulses may be so strong that, despite the will, defecation will take place.



FIG. 141.—Microscopic constituents of the stools: a, vegetable fragments; b, muscular fibers; c, white blood-corpuscles; d, saccharomycetes; e, micro-organisms; f, crystals of triple phosphate; g, fatty-acid crystals (partly from Jaksch).



FIG. 142.—Monads from the feces: a, *Trichomonas intestinalis*; b, *Cercomonas intestinalis*; c, *Ameba coli*; d, *Paramoecium coli*; e, living monads; f, dead monads (Jaksch).

**Involuntary Discharges.**—In some forms of disease the irritability of the anospinal center is so great that when the rectum is only partially filled defecation takes place, and there is no power to retard it. Discharges under these circumstances are said to be involuntary.



**Involuntary and Unconscious Discharges.**—If by reason of disease or of injury the middle or the upper portions of the cord become so disorganized as to cut off communication with the brain, while at the same time the lower portion is in normal condition, the act of defecation takes place when the rectum becomes sufficiently distended to stimulate the anospinal center to action; but there is no power to retard nor is there any consciousness of it, since the connection with the brain is severed. Under these circumstances the discharges are involuntary and unconscious. If the lumbar portion of the cord is the seat of injury or of disease to such an extent as to destroy this center, the sphincter is permanently relaxed, and the feces are discharged as fast as they reach the anus.

## THE BLOOD.

The office of the blood is twofold: 1. It carries to the tissues of the body the materials which they need for their nourishment, and, in the case of glands, for their secretion; and 2. It takes from the tissues the materials which result from their destructive metabolism—waste materials—which it carries to those organs whose function it is to eliminate them, as, for instance, urea to the kidneys. The blood may be likened to a river which bears to the inhabitants along its banks their daily food, and into which at the same time their waste is discharged and carried to the sea.

**Physical Properties of Blood.**—Blood is in general red in color and alkaline in reaction when tested with litmus-paper, and has in man a specific gravity of about 1060, although this varies in men, women, and children, being less in the last, except at birth, when it is 1066. The specific gravity of the corpuscles is greater than that of the plasma.

**Method of Obtaining the Specific Gravity of Blood.**—The most convenient method is that of Roy. In applying it, mixtures of glycerin and water are made of different specific gravities, and blood is dropped into these until one is found in which the drop of blood will neither rise nor sink. Knowing the specific gravity of this mixture, that of the blood, being the same, is also known.

**Color of Blood.**—Although blood is generally said to be red, still this color is subject to considerable variation. Thus, venous blood is variously described as bluish red, reddish black, deep purple, dark purplish red, dark blue, and dark purple, while arterial blood is a bright scarlet. The color of blood depends on hemoglobin or its derivatives. In the blood of an animal that has been suffocated, where the purplish or blackish color is most pronounced, the coloring-matter is almost entirely hemoglobin, while in arterial blood the oxyhemoglobin predominates, and in ordinary venous blood there is a mixture of hemoglobin and oxyhemoglobin.

When the coloring-matter passes out from the corpuscles into

the fluid portion of the blood the blood is said to be *laqueous*. This solution of the hemoglobin may be brought about in many ways, as by adding distilled water or a solution of sodium chlorid or other neutral salt, provided that the solution is not *isotonic*. An isotonic solution is one in which the amount of the salt present does not change the form of the red corpuscles or dissolve out its coloring-matter. In the case of sodium chlorid, this is for human blood a solution having a percentage of 0.9.

**Reaction of Blood.**—The alkalinity of blood is a property essential to life, and, so far as the plasma is concerned, depends upon the presence of sodium carbonate and phosphate. The alkalinity is not always the same; it is least in the morning, increases in the afternoon, and diminishes at night. It increases during digestion and after muscular exercise. It is said that the blood becomes acid immediately before death in cases of cholera, and also in the condition of unconsciousness called coma, which occurs sometimes in diabetes.

**Odor of Blood.**—Blood has an odor which is said to be characteristic of the species of animal from which it is taken. The odor is usually very slight, but it may be intensified by the addition of sulphuric acid.

**Taste of Blood.**—The sodium chlorid which blood contains gives to it a salty taste.

**Quantity of Blood.**—The amount of blood in the body of a human adult is about 7.7 per cent., one-thirteenth of his weight; some authorities state one-eighth, and others one-fourteenth. In a newborn child it is about one-nineteenth. During the latter half of the period of pregnancy it is increased, and it is also increased during digestion.

There are various methods of determining the quantity of blood in the body; that of Welcker is, perhaps, the best known. It consists in opening a vein of an animal and withdrawing blood, which is measured and defibrinated. This is then divided into portions, each of which is diluted with a different amount of water, which thus gives solutions of different colors; these serve subsequently as standards of comparison. The animal is then bled until all the blood that will flow has been withdrawn; this is defibrinated, and sufficient salt solution is injected into the vessels to wash out the blood that remains. This is continued until the fluid comes out colorless. The body is then cut up into small pieces and mixed with saline solution, and this then filtered, and the filtrate, together with the washings of the blood-vessels, is added to the defibrinated blood. The mixture is measured, and diluted with water until its color corresponds with that of one of the standard solutions, when the calculation can be made which will determine the total amount of blood in the body. It is necessary, of course, to include the quantity of blood which was first withdrawn to make the standard solutions.

**Temperature of Blood.**—The temperature of the blood varies greatly in the different parts of the circulatory apparatus. The mean temperature may be stated as  $39^{\circ}\text{C}$ .; that of the superior vena cava,  $36.78^{\circ}\text{C}$ .; the right side of the heart,  $38.8^{\circ}\text{C}$ .; the left side of the heart,  $38.6^{\circ}\text{C}$ .; the aorta,  $38.7^{\circ}\text{C}$ .; the portal vein,  $39.9^{\circ}\text{C}$ .; the hepatic vein,  $41.3^{\circ}\text{C}$ . The temperature of the blood in the hepatic vein is the highest in the body, and it varies from  $39.5^{\circ}\text{C}$ . at the beginning of digestion to  $41.3^{\circ}\text{C}$ . at the time when the process is most active. The blood in the right side of the heart is made warmer by its proximity to the liver, while in its circulation through the lungs it loses heat, and is therefore cooler in the left side of the heart. In the portions of the body exposed to the air, as in the skin, the temperature of the blood may be doubtless as low as  $36.5^{\circ}\text{C}$ .

**Distribution of Blood.**—

The distribution of blood in the body is as follows: In the heart, lungs, and great blood-vessels, one-fourth; in the skeletal muscles, one-fourth; in the liver, one-fourth; in the rest of the body, one-fourth.

**Microscopic Structure of the Blood.**—When examined by the microscope the blood is seen to be composed of *corpuscles* suspended in a fluid, the *plasma* or *liquor sanguinis*.

**Blood-corpuscles.**—By means of a *hematocrit* (Fig. 143) the average percentage of corpuscles in human blood has been found to be about 48 for males, and 43.3 for females,

FIG. 143.—Hematocrit.

while for children of from six to thirteen years it is 45. In making this determination the blood is mixed with a measured quantity of a  $2\frac{1}{2}$  per cent. solution of potassium bichromate, and then placed in a tube which is revolved very rapidly, or, as it is expressed, *centrifugalized*. The corpuscles accumulate at the bottom of the tube, while the plasma remains above them, and the volume can be determined by simply reading the scale.

The corpuscles of the blood are of three varieties: (1) Red corpuscles; (2) colorless corpuscles; and (3) plaques.

*Red corpuscles* in human blood are circular, biconcave, non-

nucleated disks, having an average diameter of  $7.7\ \mu$ , some of them being as small as  $4.5\ \mu$ , while others are  $9\ \mu$ . The small corpuscles are termed *microcytes*, and are regarded as not fully developed corpuscles. In chronic anemic conditions some have been found as large as  $14\ \mu$ , and others as small as  $2.2\ \mu$ .

*Number of Red Corpuscles.*—The number of red corpuscles in a cubic millimeter of the blood of a male adult has been reckoned at 5,000,000; in that of a female, 4,500,000. In a man weighing 68 kilos there are estimated to be 25,000,000,000,000, presenting a superficial area of about 3200 square meters. In all the blood of the body in health their number is consequently enormous.

There are various methods of determining the number of red corpuscles: (1) By the *hematocrit* (p. 270); (2) by the *hemacytometer*.

*By the Hematocrit.*—This instrument has been described, and its use explained, for determining the relative proportion of corpuscles and plasma. It has been ascertained that each volume of corpuscles, as indicated by the scale, represents 97,000 corpuscles.

FIG. 144.—Blood-corpuscles: a, blood-plaques or third corpuscles; b, red corpuscles; c, white corpuscles (Eberth and Schimmelbusch).

*By the Hemacytometer.*—There are three forms of this instrument—that of Gowers, that of Thoma-Zeiss, and that of Oliver.

*Gowers' hemacytometer* consists of a pipet, which contains 995 cu.mm. when filled to the mark made on the tube, a glass mouthpiece is connected with this pipet by means of rubber tubing; a capillary tube, holding 5 cu.mm. when filled to the mark, this also having a mouthpiece and rubber tubing; a brass plate, with a glass slide, on which is a cell having a depth of  $\frac{1}{3}$  mm. and divided on the bottom into  $\frac{1}{16}$  mm. squares, the cell in use being covered by a cover-glass; a jar, in which the blood to be examined is diluted; a glass rod, for staining; and a needle, for pricking the finger to obtain blood.

A solution of sodium sulphate is made having a specific gravity of 1025, which corresponds to the specific gravity of blood-plasma, and this is sucked up into the pipet to the mark indicating 995 cu.mm. This is then deposited in the jar. The finger is pricked with the needle, the amount of projection of which can be regulated by a screw, and 5 cu.mm. of blood sucked up into the capillary tube, and this is then deposited in the jar with the saline solution, and the mixture thoroughly stirred with the glass rod. A drop of the mixture is then placed in the cell and a cover-glass

placed over it. The brass plate is placed on the microscope, with a magnifying power of 400 diameters. In a short time the red corpuscles settle to the bottom of the cell, and the number con-

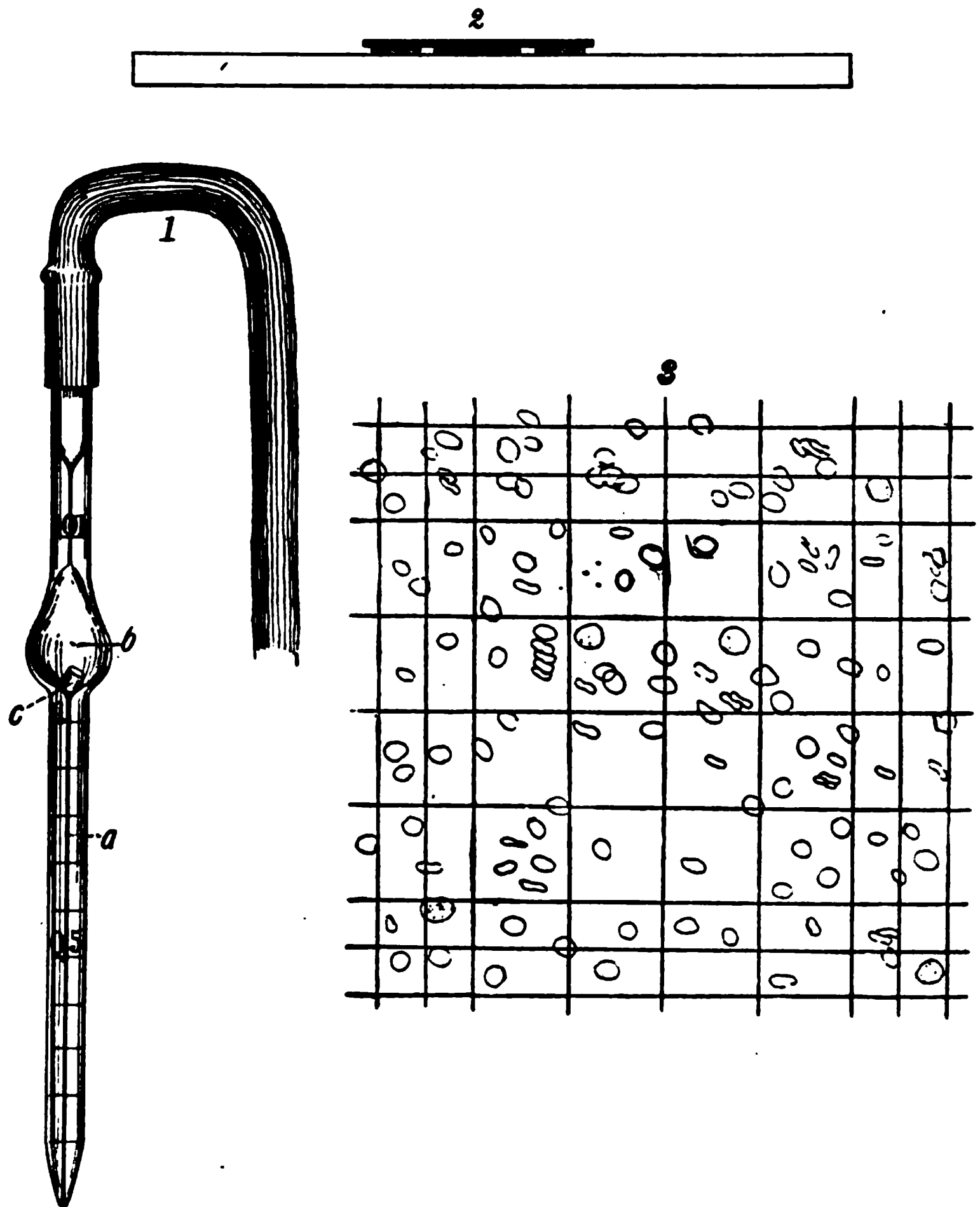


FIG. 145.—Thoma-Zeiss hemacytometer. 1. Mixing apparatus: *a*, capillary tube in which the blood is taken; *b*, chamber for mixing the blood with the diluting solution; *c*, glass ball to aid in mixing the blood with the diluting solution. 2. Cross-section of the chamber in which the blood is counted. 3. Section of the field on which the blood is counted, showing thirty-six squares.

tained in 10 squares are counted, added together, and multiplied by 10,000; the product is the number in 1 cu.mm. of blood.

*Thoma-Zeiss Hemacytometer* (Fig. 145).—This is quite simple to use, inasmuch as the blood is drawn and diluted in one in-

strument. It consists of a pipet with mouthpiece and tubing connecting the two. It is carefully graduated, and has a bulb which contains 100 times as much as the capillary tube when filled to mark 1. In this bulb is a glass bulb which aids in the mixing of the blood and saline solution. There is also a glass slide (Fig. 145, 2) having a covered disk. On the surface of this 1 cu.mm. is divided into 400 squares, each  $\frac{1}{20}$  mm. This is surrounded by a cell of such height that when a cover-glass is placed upon it its under surface will be  $\frac{1}{10}$  mm. above the disk. The finger being pricked, the blood is drawn into the capillary tube as far as 1 on the scale; the saline solution, Hayem's fluid (see below) or 3 per cent. sodium chlorid solution, is then drawn up to 101. The pipet is then shaken so as to mix the blood and solution thoroughly, and a drop of the mixture placed on *m* and covered with a cover-glass. The volume of blood above each of the squares will be  $\frac{1}{4000}$  cu.mm. The corpuscles in from 10 to 20 squares are counted, and by dividing this number by the number of squares taken, the average per square will be obtained. This multiplied by  $4000 \times 100$  equals the number of corpuscles in a cubic millimeter of blood. For the depth of the cell being  $\frac{1}{10}$  mm., and the area of each square being  $\frac{1}{400}$  sq.mm., the volume of blood on each square would be  $\frac{1}{4000}$  cu.mm. Inasmuch as the blood has been diluted 100 times, 1 cu.mm. of blood withdrawn from the vessels would contain 400,000 times the corpuscles in 1 square.

Hayem's fluid consists of sulphate of sodium, 5 grams; sodium chlorid, 1 gram; corrosive sublimate, 0.5 gram; dissolved in 200 c.c. of distilled water.

*Oliver's Hemacytometer* (Fig. 146).—This apparatus consists of a measuring pipet, *a*; a dropper, *b*; a mixing tube, *c*. A small amount of blood is measured in the measuring pipet and mixed in the mixing tube with Hayem's fluid. The tube is then held between the fingers, and the light of a wax candle, held about  $2\frac{1}{2}$  meters from the eye, in a dark room, is looked at, the tube being held edgewise. Enough fluid is added to make the flame appear as a bright line through the mixture. If the red corpuscles are present to the number of 5,000,000 to the cubic millimeter, the surface of the mixture will stand at 100. If the number is less, it will not require so much of the fluid to make the mixture transparent; while if the number is in excess of normal it will require more. The graduations on the tube are percentages of the normal standard; thus if 100 represents 5,000,000 corpuscles, 80 would represent 4,000,000.

Many observations have shown that the number of red corpuscles is subject to considerable variation even in the same individual. Muscular exercise, and even massage, which is passive exercise, increase the number; while food diminishes it.

The blood of persons living in high altitudes has shown the

presence of red corpuscles to the number of 8,000,000 per cu.mm. It does not necessarily follow, however, that this is an absolute increase, for it may be due to loss of the water of the blood, caused by increased evaporation from the body, and to increased

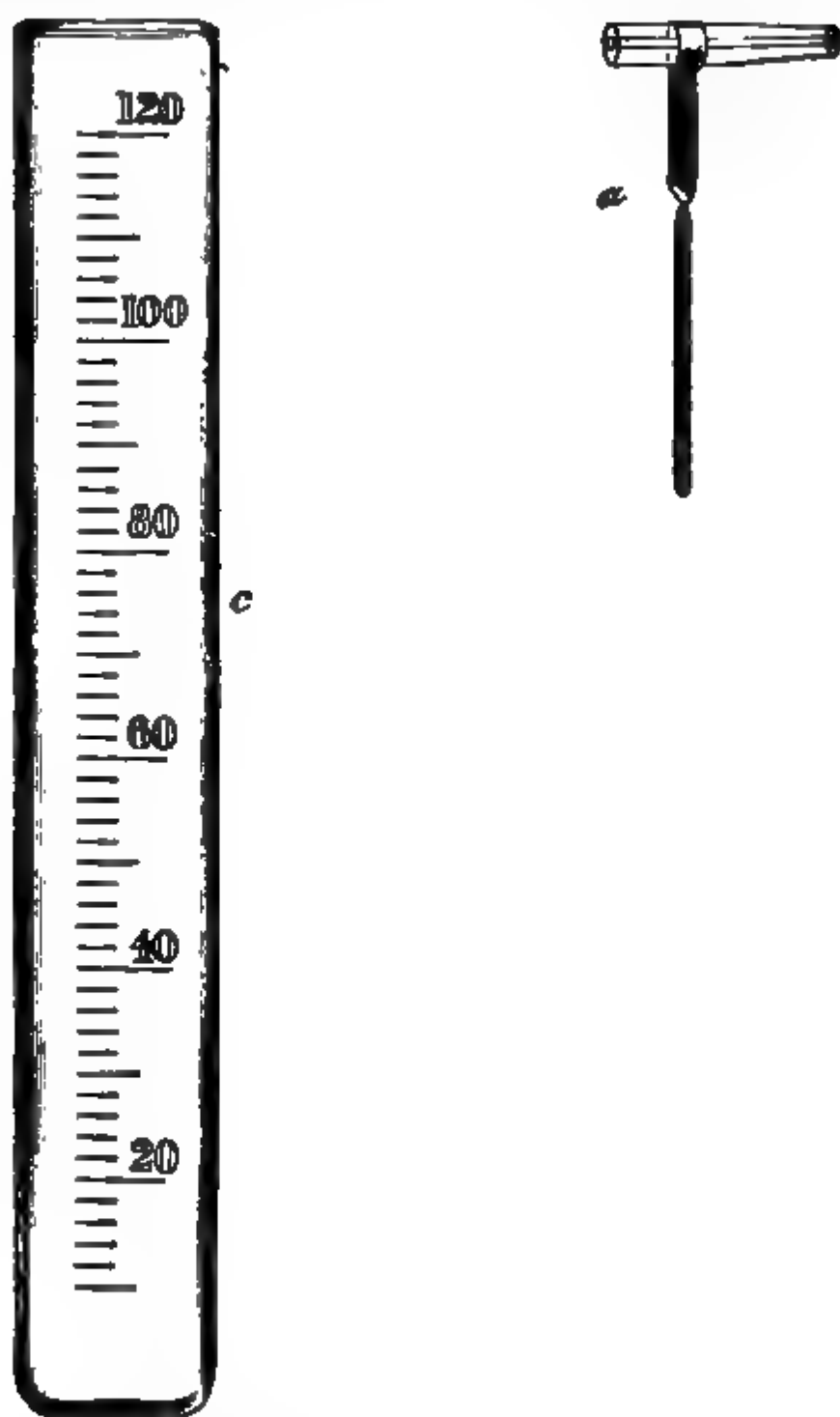


FIG. 146.—Oliver's hemacytometer: *a*, measuring pipet; *b*, dropper to contain Hayem's fluid; *c*, mixing tube graduated in percentages; *d*, mode of making the observation (this must be done in a dark room); *a*, *b*, and *c* are natural size.

arterial tension, by which the amount of lymph is increased. In conditions of apparent health so small a number as 1,600,000 has been found. In newborn children, 5,000,000 per cu.mm. have been estimated.

*Color of the Red Corpuscles.*—A single corpuscle is of a



yellowish or amber color, and the red color of the blood appears only when the corpuscles are in thick layers or in masses.

*Structure of Red Corpuscles.*—There is a difference of opinion among histologists as to the minute structure of these bodies. Schäfer describes it as follows: "Each red corpuscle is formed of two parts, a colored and a colorless, the former being a solution of hemoglobin; the latter, the so-called stroma, which is by far the smaller quantity, being composed of various substances, chief among these being lecithin and cholesterin, together with a small amount of cell-globulin." According to this view, the colorless stroma serves as an envelope to contain the hemoglobin in solution.

By other authorities, of whom Rollett may be regarded as an exponent, the entire corpuscle is made up of an elastic structure, the stroma, the outer portion of which is denser than the inner, and having in its interstices the coloring-matter together with lecithin, cholesterin, and globulin.

In discussing this subject, Gamgee, in Schäfer's *Text-Book of Physiology*, says: "Without attempting to speculate beyond the facts which we possess, it may, however, be assumed that hemoglobin exists in the blood-corpuscles in the form of a compound with a yet unknown constituent of the corpuscle. This compound, the existence of which we are forced to assume, is characterized by remarkable instability, for it is decomposed, setting free the hemoglobin, which then passes into solution (1) when the blood-plasma or serum, in which the corpuscles are suspended, is diluted; (2) when certain substances act upon the corpuscles (ether, chloroform, salts of the bile-acids, certain products of putrefaction); (3) by the action of heat, by alternate freezing and thawing, by induction shocks, etc."

The red corpuscles are exceedingly flexible, as may readily be seen by watching them in the circulation of the web of a frog's foot. At times they will be so stretched out as to pass through a vessel whose diameter is smaller than is theirs when in a circular shape; or sometimes they may be seen bent over the projection made by the junction of two vessels, one portion being within each, until, one current being the stronger, they are carried forward by it, resuming their circular shape as soon as the size of the vessel permits.

The human red corpuscles possess in adult life no nuclei. This is true of all mammals. Up to the fourth month of fetal life the blood of the human embryo contains nucleated red corpuscles. It is uncertain, however, whether these develop into the non-nucleated forms. In other vertebrates the corpuscles are nucleated.

*Chemical Composition of Red Corpuscles.*—An analysis of the red corpuscles of human blood shows the presence of both organic and inorganic compounds. The percentage of organic ingredients in dried human corpuscles in one analysis was as follows: Proteids



and nuclein, 12.24 ; hemoglobin, 86.79 ; lecithin, 0.72 ; cholesterin, 0.25. The nucleoproteid is called by some writers cell-globulin. The inorganic substances are potassium and sodium salts ; potassium constituting 40.89 per cent. of the total ash, while of sodium there is only 9.71 per cent.

*Hemoglobin*.—This is the term applied to the highly complex, iron-containing, crystalline coloring-matter, which forms the most important constituent of the colored corpuscles of the blood, and by virtue of which they perform their function as the oxygen-carriers of the organism (Gamgee). It constitutes 95 per cent. of the solid matter of the red corpuscles, and in the adult male there are about 14 grams for each 100 grams of blood, or in all about 750 grams. When united with a molecule of oxygen it forms *oxyhemoglobin* ; when it exists by itself, without this molecule, it bears the name of *hemoglobin* or *reduced hemoglobin*. Because of its property of serving as an oxygen-carrier it is spoken of as a *respiratory pigment*. The hemoglobin in the blood of different animals varies both physically and chemically, so that some writers speak of *the hemoglobins* ; but Gamgee thinks this is unnecessary and misleading, inasmuch as the proportion in which iron, the characteristic element in the blood coloring-matter, occurs, is absolutely the same in many animals ; and, besides, there is abundant evidence in favor of the view that the optical and physiologic properties of hemoglobin depend upon the identical “typical nucleus” in all animals.

When hemoglobin is decomposed in the presence of oxygen, it breaks up into a proteid, *globulin*, which constitutes 96 per cent. of it, and *hematin*, of which there is 4 per cent. If this decomposition takes place without oxygen, instead of *hematin*, *hemochromogen* is produced. It is to this latter substance that hemoglobin owes its characteristic property of taking up oxygen.

The exact percentage-composition of the hemoglobin of human blood has not been determined ; that of the dog, as analyzed by Jaquet, is as follows : C, 53.91 ; H, 6.62 ; N, 15.98 ; S, 0.542 ; FeO, 0.333 ; O, 22.62. The molecular formula is  $C_{758}H_{1203}N_{195}S_{33}FeO_{218}$ , making the molecular weight 16.669. Gamgee has calculated for the hemoglobin of the ox the following :  $C_{759}H_{1208}N_{210}S_2FeO_{204}$ . Bunge says, in reference to the molecular weight of hemoglobin : “The enormous size of the hemoglobin-molecule finds a teleological explanation, if we consider that iron is eight times as heavy as water. A compound of iron which would float easily along with the blood-current through the vessels could only be secured by the iron being taken up by so large an organic molecule.” Hemoglobin forms crystals in the absence of oxygen.

*Hemoglobinometers*.—There have been various methods devised to determine the amount of hemoglobin in the blood. Those which are commonly used are sufficiently exact for clinical purposes,

though undoubtedly the determination of the amount of iron would give more precise results; the ordinary methods depend upon the color.



FIG. 147.—Oliver's hemoglobinometer: *e*, glass cell for receiving the blood from the pipet (the dilution is effected within the cell itself); *a*, standard graduations made of tinted glass. To avoid multiplying these unduly, they are furnished in tens per cent., the intermediate divisions of the scale being obtained by superposing tinted glass riders in a graduated series from 1 to 9. (These riders are not represented in the figure.) The apparatus is shown of the natural size.

*Oliver's Hemoglobinometer* (Fig. 147).—Some of the blood, the amount of whose hemoglobin is to be determined, is diluted and placed in the glass cell *e*; the color of this diluted blood is then compared with the series of tinted glasses, the color of each

of which corresponds to a known percentage of hemoglobin. The one that corresponds to the color of the sample of blood determines the percentage of hemoglobin in the blood under examination.

*Gowers' Hemoglobinometer* (Fig. 148).—This apparatus consists of two glass tubes having the same diameter. *d* contains glycerin-jelly colored with carmine, so that the color represents that of blood diluted one hundred times with water. The finger is pricked with the needle *f*, and the blood is sucked up into the pipet *b* to the 20 cu.mm. mark, and then blown out into the tube *c*, distilled water being added in drops from *a* until the color of the diluted blood corresponds with the color in *d*. The tube *c* is so graduated that when filled to 100 with diluted blood its color corresponds to



FIG. 148.—Gowers' hemoglobinometer: *a*, pipet bottle for distilled water; *b*, capillary pipet; *c*, graduated tube; *d*, tube with standard dilution; *f*, lancet for pricking the finger.

that of *d*, which would consequently represent the color of normal blood. If, therefore, in order to produce a color corresponding to that in *d*, water must be added to fill the tube to a higher level than 100, the hemoglobin is above normal; while if, on the other hand, the color is produced below 100, then the graduation at that point represents the percentage of the normal. Thus if at 75 the corresponding color is reached, only 75 per cent. of the normal amount is present.

*Von Fleischl's Hemometer* (Fig. 149).—This consists of a stand carrying a white reflecting surface, *e*, and having a platform below upon which slides a glass wedge colored red, *b*. On the platform is a compartment, *d*, divided into two by a vertical partition. The one which is directly above the colored wedge is filled with distilled water. Into the other, a small amount of distilled water is placed.

The finger is pricked and the blood which is to be examined is drawn up into a tube provided for that purpose. The blood is then put into the second compartment, which is afterward filled with distilled water. The milled head *f* is then turned, and this carries along with it the wedge of glass. When the colors, as seen by transmitted artificial light, in the contents of both compartments correspond, the percentage of hemoglobin in the blood

FIG. 149. — Von Fleischl's hemometer: *a*, stand; *b*, narrow wedge-shaped piece of colored glass fitted into a frame (*c*), which passes under the chamber; *d*, hollow metal cylinder, divided into two compartments, which hold the blood and water; *e*, white plate from which the light is reflected through the chamber; *f*, screw by which the frame containing the colored glass is moved; *g*, capillary tube to collect the blood; *h*, pipet for adding the water; *i*, opening through which may be seen the scale indicating percentage of hemoglobin.

may be ascertained by reading the scale at *i*. This instrument should be used in a dark room.

*Oxyhemoglobin*.—It is this substance which gives to arterial blood the scarlet color which is so characteristic of it; here, however, it occurs, not by itself, but together with hemoglobin (reduced hemoglobin) and in excess of the latter. In venous blood the two also coexist, but the hemoglobin is in excess, while in the blood of asphyxia the coloring-matter is almost entirely hemoglobin.

The hemoglobin of some animals, as the guinea-pig, cat, and dog, crystallizes very readily, while that of man, and the mammals generally, forms crystals with more difficulty. To obtain crystals of oxyhemoglobin, the blood should be mixed in a test-tube with one-sixteenth its volume of ether and the tube shaken with considerable force. The coloring-matter passes into the plasma, and the blood becomes lakey. If the tube is then placed on ice, in a short time the crystals will form and can be examined under the micro-

scope. The form of the crystals varies in different animals (Fig. 150). In the guinea-pig, the blood of which is easily obtained, and whose oxyhemoglobin crystallizes readily, they are rhombic tetrahedra.

*Derivatives of Hemoglobin.*

—Besides oxyhemoglobin, the properties of which have already been given, there are various derivatives of hemoglobin; among them are the following:

*Carbon-monoxid Hemoglobin.*—As one molecule of hemoglobin combined with one of oxygen forms oxyhemoglobin, so one molecule of hemoglobin united with one of carbon monoxid forms carbon-monoxid hemoglobin. There is, however, one striking difference in the two combinations. In the former the oxygen is readily displaceable, while in the latter the compound is a very stable one, although Gamgee has shown

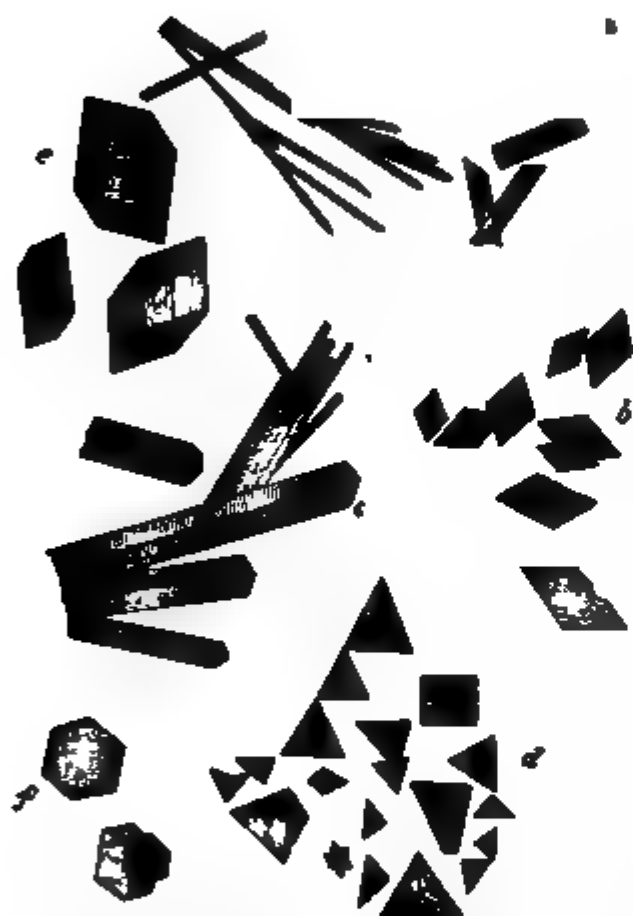


FIG. 150.—Crystallized hemoglobin: a, b, crystals from venous blood of man; c, from the blood of a cat; d, from the blood of a guinea-pig; e, from the blood of a hamster; f, from the blood of a squirrel (after Frey).

that by the long-continued passage of neutral gases through solutions of CO-hemoglobin the CO is gradually driven out, and reduced hemoglobin is obtained. Carbon monoxid is the gas formed when combustion is incomplete, such as is produced by the charcoal furnace used in France for suicidal purposes; the charcoal fumes when inhaled in sufficient quantity produce fatal results. It is also a constituent of illuminating-gas, where it exists in proportions ranging from 7.9 to 28.25 per cent., and is not infrequently the cause of death. The gas displaces the oxygen and unites so firmly with the hemoglobin that even with artificial respiration it cannot be dis-

placed. The color of carbon-monoxid hemoglobin is a cherry red, and the blood in persons poisoned with it has this color.

*Nitric-oxid Hemoglobin.*—Nitric oxid will also displace the oxygen from oxyhemoglobin, and the *nitric-oxid hemoglobin* which results is a more stable compound than carbon-monoxid hemoglobin. It consists of one molecule of hemoglobin and one of nitric oxid.

*Carbo-hemoglobin.*—Hemoglobin will also unite with carbon dioxid, and it has been demonstrated that each gas acts with reference to hemoglobin independently of the others—*i. e.*, that even when a solution of hemoglobin is nearly saturated with oxygen, it can still take up as much carbon dioxid as when no oxygen is present. It has been suggested that the explanation of this is that the oxygen unites with the portion which gives the color, hemochromogen, and the  $\text{CO}_2$  with the proteid portion.

*Methemoglobin.*—This is regarded as being chemically the same as oxyhemoglobin, except that the union of the hemoglobin and oxygen is more stable. Oxyhemoglobin may be converted into methemoglobin by the action of many substances, among which may be mentioned potassium ferricyanid, nitrites, potassium permanganate, etc. It has been demonstrated that when this conversion takes place the whole of its oxygen passes into such intimate relationship with the hemoglobin that it cannot be displaced by carbon monoxid. Methemoglobin also crystallizes, the form of the crystals being the same as that of oxyhemoglobin. Methemoglobin is the form in which the blood-coloring matter exists when blood has been for a considerable time exposed to the air. It is also known as *reduced hematin*.

*Hematin.*—Various formulæ have been given to represent this substance. That of Hoppe-Seyler is  $\text{C}_{34}\text{H}_{35}\text{N}_4\text{FeO}_5$ . When oxyhemoglobin is decomposed by acids or alkalies in the presence of oxygen *hematin* results.

*Hemin.*—This is chemically *hematin hydrochlorid*,  $\text{C}_{34}\text{H}_{35}\text{N}_4\text{FeO}_5\text{HCl}$ . If to a drop of blood on a glass microscopic slide is added a drop or two of glacial acetic acid and the mixture is boiled, after evaporation there will be found, if examined by the microscope, brownish prismatic crystals of hemin. These were discovered by Teichmann, and are also known by his name (Fig. 151). These crystals are so characteristic that this method of producing them is very much used to determine whether colored spots or stains are blood or not. The explanation of the changes which take place is as follows: The hemoglobin is decomposed by the action of the acetic acid into hematin and a proteid; and at the same time the sodium chlorid is decomposed, and the hydrochloric acid which is set free unites with the hematin. If this test is used in the case of old blood-stains, from which the sodium chlorid may

have been washed out, it is necessary to add a small crystal of the salt to the acid before boiling.

*Hemochromogen*.—This is also called *reduced hematin*, and results when hemoglobin is decomposed by alkalies, or acids, in the absence of all oxygen. Its crystallizability has not been demonstrated. Gamgee questions whether hemochromogen exists preformed in hemoglobin and its compounds.

*Hematoporphyrin*.—If to hematin strong sulphuric acid is added, the iron is dissolved out, making ferrous sulphate, and *hematoporphyrin* or *iron-free hematin* remains. It is regarded by some as isomeric with bilirubin. The formula as given by Hoppe-Seyler is  $C_{34}H_{36}N_4O_6$ . It has in acidulated alcoholic solutions a purple color, assuming a bluish-violet tint when made strongly acid; but alkaline solutions are red. Solutions of this substance "exhibit a magnificent fluorescence" (Gamgee). It is found in small amount in normal urine, and in large quantity in chronic poisoning from the use of sulphonal.



FIG. 151. — Hemin, or Teichmann's crystals, from blood-stains on a cloth (Huber).

*Hematoidin*.—In blood-clots, such as form in apoplexy, where a blood-vessel of the brain ruptures, a crystalline substance is found, to which Virchow gave the name *hematoidin*. It is beyond question a derivative of hemoglobin. Its formula is given as  $C_{16}H_{18}N_2O_3$ , and it is identical with bilirubin.

*Histohematins*.—In the muscles and other tissues of the body coloring-matters are found which are called *histohematins*, which may be related to hemoglobin, but the relationship has not as yet been established.

*Spectra of Hemoglobin and its Derivatives*.—Before discussing the spectra of hemoglobin and its derivatives, it will not be inappropriate to describe the spectroscope and its application to the differentiation of the coloring-matters of the blood in the varied forms in which we have found them to occur. For a more detailed description of spectrum analysis our readers are referred to the many excellent treatises on physics. The wonderful adaptability of spectrum analysis to the solution of many physiologic problems may be illustrated by the statement that by its means  $\frac{1}{3000000}$  of a milligram of sodium can be detected, and a corresponding delicacy of analysis is true of other substances; thus the rapid absorption and diffusion of certain substances have been determined by the spectroscope. Roscoe, in his *Spectrum Analysis*, states that twenty-four minutes after injecting 3 grains of lithium salt under the skin of a guinea-pig the lithium is found to be present in the crystalline lens and every part of the body, it only

## PLATE I.

1. Solar spectrum with Fraunhofer lines. 2. Absorption spectrum of a concentrated solution of oxyhemoglobin; all the light is absorbed except in the red and orange. 3. Absorption spectrum of a less concentrated solution of oxyhemoglobin. 4. Absorption spectrum of a dilute solution of oxyhemoglobin, showing the two characteristic bands. 5. Absorption spectrum of a very dilute solution of oxyhemoglobin, showing only the  $\alpha$ -band. 6. Absorption spectrum of a dilute solution of reduced hemoglobin, showing the characteristic single band (to be compared with spectrum 4). 7. Absorption spectrum of a dilute solution of carbon-monoxide-hemoglobin (to be compared with spectrum 4). 8. Absorption spectrum of methemoglobin. 9. Absorption spectrum of acid hematin (alcoholic solution). 10. Absorption spectrum of alkaline hematin (alcoholic solution) (modified from MacMunn, *The Spectroscope in Medicine*).





being necessary to burn a portion of the animal tissue in a colorless flame in order to see the bright-red line of lithium: ten minutes after the injection it is found in small quantities in the lens, but plentifully elsewhere; while four minutes after the injection lithium is not found in the lens, but plentifully in the aqueous humor of the eye, and in the bile. The same rapid diffusion occurs in the human body. The crystalline lenses of persons who have been operated upon for cataract have been examined, these persons having previously to the removal of the lens been given by the stomach 20 grains of carbonate of lithium; in three and a half hours it was detected in each particle of the lens.

When a sunbeam passes through a glass prism, the differently

FIG. 152.—Spectroscope: P, the glass prism; A, the collimator tube, showing the slit (s) through which the light is admitted; B, the telescope for observing the spectrum.

colored rays which compose it are separated, and if, after emerging from the prism, the beam falls upon a screen, it will appear as a band of different colors, beginning with red and ending with violet; this band is the *solar spectrum* (Plate 1, Fig. 1). A *spectroscope* is an instrument for producing and observing *spectra* (Fig. 152). The beam of light which is to be studied, from whatever source it may come, passes into the *collimator tube* A, through the slit s, and its rays, being made parallel by a lens in this tube, are separated or *dispersed* by the prism P; the spectrum which results may then be examined by an observer through the *telescope* B. If the source of the light is an incandescent body, the spectrum will be a *continuous* one—i. e., there will be nothing but a band of colors, in which the red passes on to violet through

orange, yellow, green, blue, and indigo ; but if it is the sun which is the source of light, though this is an incandescent body, still its light passes through an atmosphere which absorbs certain portions of the light, and the spectrum is, therefore, crossed by dark lines, *Fraunhofer lines*. These lines are fixed, and the more distinct ones are designated by letters of the alphabet ; thus in the red are A, B, and C ; in the yellow D, etc. As the atmosphere of the sun absorbs certain parts of the light which is transmitted through it, so do many transparent substances, and the spectra of such substances are known as *absorbent spectra*, in contradistinction to continuous spectra, in which no lines or bands appear. If, therefore, the light of the sun or that from any other source of illumi-

C

FIG. 153.—The hematinometer.

FIG. 154.—The hematoscope.

nation is passed through a solution of one of these substances, in its spectrum dark bands will be seen at definite places and in definite numbers, and the identity of such substances can thus be determined. The positions occupied by these bands may be designated either by stating their relation to the Fraunhofer lines, or the wave-length of the portions of the spectrum between which absorption takes place, this being determined by a scale which is provided for this purpose.

For the description of the spectra of hemoglobin and its derivatives, and the use of the spectroscope in their differentiation, we are especially indebted to the section on "Hemoglobin," by Gamgee, in Schäfer's *Physiology*.

For studying the visible spectrum of hemoglobin, Gamgee recommends a spectroscope of the ordinary Bunsen type, provided with a single good flint-glass prism, or direct vision spectroscopes of the Browning or Hofmann patterns. If minute quantities of coloring-matter are to be investigated, microspectroscopes may be used—*i. e.*, direct vision spectroscopes adapted to the eye-piece of a compound microscope. As the source of light, he recommends a gas lamp, furnished with the Auer incandescent burner.

It is convenient to have the solutions, whose absorption-spectra are to be examined, in cells with perfectly parallel sides, and a definite width apart; such an apparatus is the *hematinometer* (Fig. 153).

The *hematoscope* or *hemoscope* of Hermann (Fig. 154) is also used for this purpose. In this apparatus the thickness of a layer of fluid can be regulated by sliding C toward F, and measured by a scale on C. F and C are glass plates through which and the intervening fluid light is transmitted for spectroscopic examination.

*Spectrum of Oxyhemoglobin* (Fig. 155).—Dilute solutions of

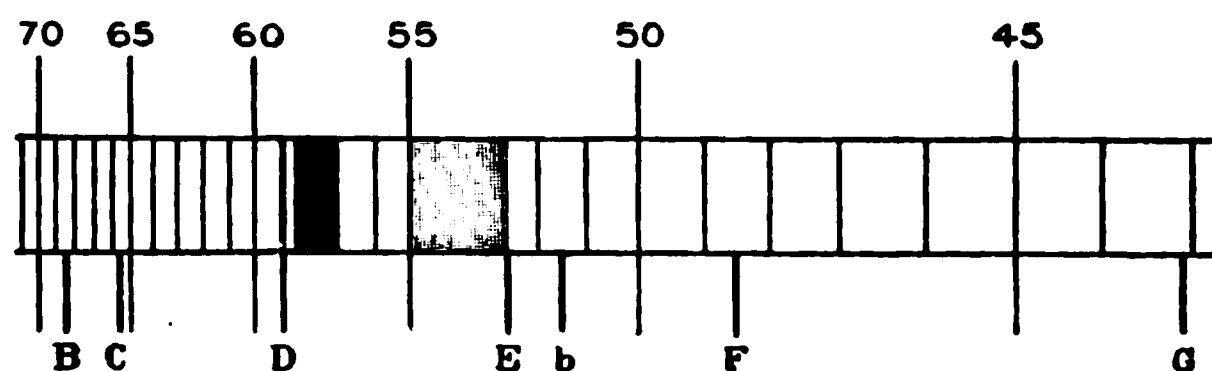


FIG. 155.—Diagrammatic representation of the absorption-spectrum of oxyhemoglobin. The numerals give the wave-lengths in hundred-thousandths of a millimeter; the letters show the positions of the more prominent Fraunhofer lines of the solar spectrum. The red end of the spectrum is to the left. The  $\alpha$ -band is to the right of D, the  $\beta$ -band to the left of E (after Rollett).

oxyhemoglobin give two absorption-bands between D and E. The band nearer D—*i. e.*, the red end of the spectrum—is known as the “ $\alpha$ -band”; the one near E is the “ $\beta$ -band,” and is broader, lighter, and less clearly defined than the  $\alpha$ -band. The center of the  $\alpha$ -band corresponds to a wave-length of 579 millionths of a millimeter ( $\lambda$  579); while the center of the  $\beta$ -band corresponds to  $\lambda$  553.8.

*Spectrum of Hemoglobin (Reduced Hemoglobin)* (Fig. 156).—Oxyhemoglobin may be reduced to hemoglobin by adding to its solutions Stokes’ reagent, which is made by dissolving 2 parts by weight of ferrous sulphate, adding 3 parts of tartaric acid, and then adding ammonia until the reaction is distinctly alkaline. When thus reduced the  $\alpha$ - and  $\beta$ -bands disappear, and the “ $\gamma$ -band” appears; this is a single band between D and E, its darkest part being nearer D than E, and corresponding to about  $\lambda$  550. If the solution is shaken with air, the appearance of the  $\alpha$ - and  $\beta$ -bands shows that oxyhemoglobin has been formed.

*Carbon-monoxid Hemoglobin.*—This derivative of hemoglobin presents two bands resembling those of oxyhemoglobin, except that they are nearer the violet end of the spectrum.

Methemoglobin and hematin have each a characteristic spectrum.

*Development of Red Corpuscles.*—This is described by Schäfer as taking place in the following manner: In the developing embryo some cells of the mesoblast become united, forming a protoplasmic network. These cells are nucleated, and their nuclei multiply, colored protoplasm forming an aggregation around them. The protoplasm of this network is hollowed out by an accumulation of fluid; in this manner the capillary blood-vessels are formed. The nuclei with their colored protoplasm are set free, becoming embryonic blood-corpuscles. The blood-corpuscles are at this period, therefore, nucleated cells. The corpuscles at this time have a diameter of from  $10\ \mu$  to  $16\ \mu$ , and are spherical. They possess the power of ameboid movement, and thus resemble

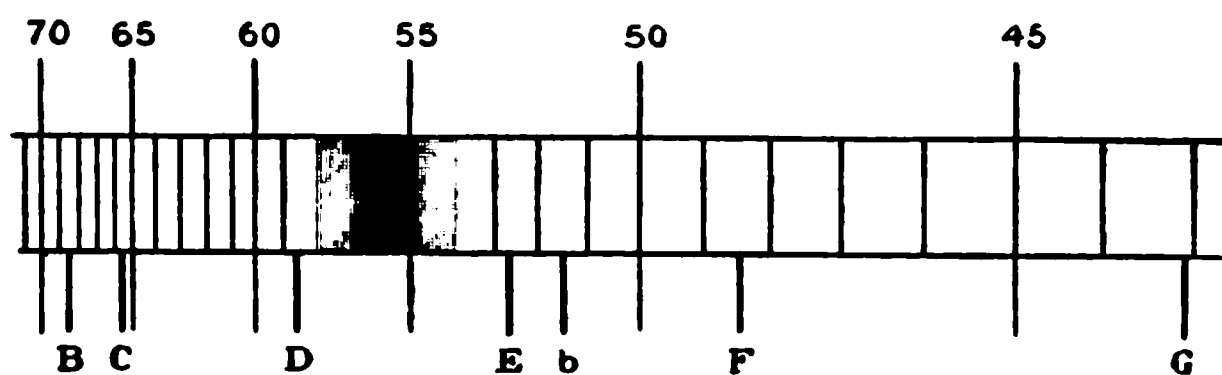


FIG. 156.—Diagrammatic representation of the absorption-spectrum of hemoglobin (reduced hemoglobin). The numerals give the wave-lengths in hundred-thousandths of a millimeter; the letters show the positions of the more prominent Fraunhofer lines of the solar spectrum. The red end of the spectrum is to the left. The single diffuse absorption-band lies between D and E (after Rollett).

the white corpuscles. It has been suggested that these should be called *blood-cells* rather than blood-corpuscles.

The liver begins to be formed about the third week of embryonic life, and about the third month occupies most of the abdominal cavity. This organ, together with the spleen, thymus, and lymphatic glands, also produces blood-cells which are nucleated, are at first colorless, and afterward acquire the characteristic color.

At a later period of embryonic life, about the second month, non-nucleated disk-shaped corpuscles make their appearance. These originate to some extent in connective-tissue cells, a portion of the cell becoming colored, and separate into globular particles, which subsequently become the discoid corpuscles. The connective-tissue cells afterward become hollowed out, and, joining with other cells which have gone through the same process, blood-vessels are formed. This later embryonic formation of blood-corpuscles does not involve the cell-nuclei, as does that of the earlier period. The nucleated cells are replaced by the non-

nucleated about the end of the fourth month, but it is still a moot question whether any of the nucleated cells are actually concerned in the formation of the non-nucleated.

Non-nucleated blood-corpuscles are also formed in the medulla or marrow of bones, and in the spleen. In the red marrow of bones are found nucleated cells possessing the power of ameboid movement, the true "marrow-cells" of Kölliker. In the protoplasm of these cells hemoglobin is formed, and this portion of the protoplasm becomes converted into the non-nucleated corpuscle. There are, besides these marrow-cells, others of smaller size, *erythroblasts*, likewise ameboid, nucleated, and colorless, which later undergo karyokinesis; the daughter-cells become colored, lose their nuclei, and are converted into the mature non-nucleated red blood-corpuscles. It is to the red marrow that is to be principally attributed the formation of the red corpuscles in adult life. This process is called *hematopoiesis*, and is a constant process, new corpuscles taking the place of the old which have outlived their usefulness. It occurs to a much greater extent than usual after hemorrhages.

In the spleen are to be found cells somewhat resembling the erythroblasts just described, and it is the opinion of some authorities that these are also sources of the red blood-corpuscles.

*Destruction of Red Corpuscles.*—The duration of a red blood-corpuscle is undetermined, but it is doubtless limited. Some authorities place its life at from three to four weeks. Old corpuscles constantly undergo disintegration and new ones appear. The fact that fewer corpuscles are found in the blood of the hepatic than in that of the portal vein, and the additional fact that biliary pigment is formed from the coloring-matter of the blood, indicate that in the liver a part, at least, of these destructive changes takes place.

The spleen is also regarded by some authorities as being an organ in which red corpuscles are destroyed. The argument advanced in favor of this theory is that some of the sustentacular or supporting cells of the splenic pulp contain colored granules which resemble the hematin of the blood; in others red corpuscles are found in various stages of disintegration. The explanation is that these large cells are engaged in the process of destroying used-up corpuscles. Opposed to this theory is the fact that the blood coming from the spleen contains no hemoglobin in solution, which it certainly would do if red corpuscles were destroyed in that organ; besides, after removal of the spleen the destruction of corpuscles apparently goes on much the same as before.

There seems to have been an idea in the minds of some that it was essential that some organ or organs should be charged with the duty of destroying the red corpuscles. This does not, how-

ever, follow. There is no reason why many of the corpuscles may not undergo disintegration in any part of the circulatory system, wherever they happen to be at the time the change takes place. The large extent of blood-vessels in the liver would account for the destruction that takes place there, without regard to any special function of this organ connected with such destruction. If, as there is reason to believe, the pigment of the bile and the urine are formed from that of the blood, the number of corpuscles daily destroyed must be very great.

*Function of Red Corpuscles.*—The red corpuscles are the carriers of oxygen from the lungs, where it is received, to the tissues, which appropriate it. This function is due to the hemoglobin, which has a great affinity for oxygen.

*Diapedesis.*—In inflammatory conditions the red corpuscles pass through the walls of the capillaries, constituting *diapedesis* (p. 290). This is not an active process, as in the case of the leukocytes, but a passive one; for while the latter can make their way through uninjured walls, it is only after these have thus migrated that through the same opening the red corpuscles can pass.

*Colorless Blood-corpuscles.*—These are also called *white corpuscles* and *leukocytes*. They consist of granular protoplasm, and contain one nucleus or more. When in a condition of rest they are spheroidal in shape, with a diameter of about  $10\ \mu$ , and possess the power of ameboid movement; their shape is constantly changing.

The *number* of leukocytes in the blood is commonly said to be, compared with the red corpuscles, as 1 to 350 or 1 to 750, or, as others state it, about 10,000 in a cubic millimeter of blood; but these figures are of very little value, so greatly do the proportions vary under different conditions. Thus Hirst found before breakfast, 1 to 1800; one hour after, 1 to 700; before dinner, 1 to 1500; after dinner (1 o'clock), 1 to 400; two hours later, 1 to 1475; after supper (8 o'clock), 1 to 550; 12 P. M., 1 to 1200. After eating the number is much increased. This increase also occurs after the loss of blood, during suppurative processes, and after the use of bitter tonics; while in a state of hunger or deficient nourishment the number is diminished. The proportion also varies in different parts of the circulatory system; thus in the splenic vein it has been found to be as 1 to 60; in the splenic artery, 1 to 2260; hepatic vein, 1 to 170; and portal vein, 1 to 740.

*Leukocytosis* is defined as a temporary increase in the number of leukocytes in the blood. It occurs normally during digestion and in pregnancy, and is seen as a pathologic condition in inflammation, traumatic anemia, various fevers, etc. *Leukocythemia* or *leukemia*, on the other hand, is a fatal disease with marked

increase in the number of leukocytes in the blood, together with enlargement and proliferation of the lymphoid tissue of the spleen, lymphatic glands, and bone-marrow. The disease is distinguished as *lymphatic*, *splenic*, *lymphaticosplenic*, *medullary* or *myelogenic*, and *lienomyelogenous*, according as the disease involves the lymphatics, the spleen, both the spleen and the lymphatics, the bone-marrow, or both the spleen and bone-marrow. It may be due to disorder of the intestines (*intestinal leukemia*), of the liver (*hepatic leukemia*), or to disease of the tonsils (*amygdaline leukemia*)—Dorland's *Medical Dictionary*.

If peptones or leech extract are injected into the blood-vessels, there is at first a diminution in the number of the leukocytes, especially the polynuclear variety; this is termed the *leukocytopenic phase*; afterward the number is increased, constituting the *leukocytotic phase*.

Acute local inflammation causes similar changes as do these injections, but the diminution in the number of leukocytes in this case largely affects the coarsely granular variety, while the after-increase is found mainly in the finely granular corpuscles (Schäfer). It has been observed that the blood clots more readily when the coarsely granular cells are relatively few in number, and Schäfer thinks this may explain the more ready clotting of blood in inflammatory conditions.

*Varieties of Colorless Corpuscles.*—Ehrlich classifies the colorless cells according to the kind of anilin stain which the majority of the contained granules take; thus cells whose granules are stained by basic dyes, as methylene-blue, he terms *basophil*; while those whose granules are stained by acid dyes, such as eosin, he calls *oxyphil* or *eosinophil*. These terms are also written *basophile*, *oxyphile*, and *eosinophile*.

Still another classification divides the colorless corpuscles into (1) *lymphocytes*, which are characterized by being small, having a round vesicular nucleus, and named from their resemblance to the leukocytes of lymph-glands, but not possessing ameboid movement; (2) *mononuclear leukocytes*, cells with a single nucleus; and (3) *polymorphous* or *polynucleated* leukocytes, characterized by having more than one nucleus or else a divided nucleus, the divisions being connected by protoplasm. Nos. 2 and 3 possess ameboid movement. It is believed by some authorities (Howell) that these varieties are simply different stages in the development of a single type of cell, the lymphocytes being the youngest and the polynucleated leukocytes the oldest. The granules of the mononuclear variety are coarser and stain more deeply with eosin than do those of the polynuclear, but constitute only about 5 per cent. of the total colorless corpuscles; while the basophil cells are not often found. Still another variety, called *hyalin*, is described; these have no granules. It should be borne in mind that it is the kind



of dye which the protoplasm takes which determines the variety of the corpuscles; the nuclei of all the leukocytes is basophil.

*Composition of Leukocytes.*—The chemical composition of leukocytes is given (Lilienfeld) as follows:

Water . . . . .	88.51
Solids . . . . .	11.49
	<hr/>
	100.00

The solids are:

Proteid . . . . .	1.76	Lecithin . . . . .	7.51
Nuclein . . . . .	68.78	Fat. . . . .	4.02
Histon (i. e., proteid part of the nucleoproteid) . . . . .	8.67	Cholesterin . . . . .	4.40
		Glycogen . . . . .	0.80

This analysis of the cells is of those from the thymus, but we are justified in concluding that the colorless corpuscles of the blood which originate from lymphoid structures have a similar composition. It is, however, impossible to investigate the colorless blood-corpuscles by macrochemical methods. Micro-chemically they can be shown to contain fat and glycogen (Halliburton).

*Functions of the Colorless Corpuscles.*—The movements which occur in protoplasm, known as ameboid movements, have been already described (p. 24). This power is possessed by the leukocytes, by virtue of which they pass through the walls of the capillary blood-vessels, this power being *diapedesis* or *migration*. There is no doubt that this occurs normally to a certain extent, but to a much greater extent under abnormal conditions, as in inflammations. When these migrated leukocytes accumulate outside the blood-vessels, and have lost their vitality, they constitute *pus*.

*Phagocytosis.*—Metschnikoff has advanced the theory that one of the important functions of the leukocytes is to ingest and digest bacteria; this constitutes *phagocytosis*. In this process the polynucleated cells are the most active. There is no doubt that by virtue of their ameboid movement the leukocytes do surround and take into their protoplasm foreign matter, and if bacteria are present they are likewise ingested, but whether they are thus taken in while in a living state and destroyed, or only after their vitality has left them, is a question. Those who favor the theory look upon the leukocytes as the protectors of the human race against the incursions of infectious diseases, if their vitality is sufficient to overcome and destroy the bacteria of these diseases; whereas if the bacteria are the more powerful, then the disease obtains a foothold. A person is said to be *immune* when on exposure to a communicable disease, such as scarlet fever, measles, etc., he does not contract it, and the explanations which have been

given to account for this *immunity* are many and various. One of these is the "phagocytosis theory of Metschnikoff": That "immunity against infection is essentially a matter between the invading bacteria on the one hand and the leukocytes of the tissues on the other; that during the first attack of the disease the white blood-corpuscles gain a tolerance to the poisons of the bacteria, and so are able to resist the next incursion of the enemy." At the present time, however, the theory of immunity which is most generally accepted is that known as "the lateral-chain theory" of Ehrlich, for the explanation of which the reader is referred to text-books on Pathology. The phagocytotic power of the leukocytes is also manifested in their destruction of the products of inflammation.

It is believed that the colorless corpuscles are concerned in the process of coagulation of the blood (p. 294).

For the consideration of other properties of the leukocytes, the reader is referred to pages 24, 25, 293, and 300.

*Development of Colorless Corpuscles.*—The first leukocytes are formed from the embryonic cells of the mesoblast, and afterward from lymphatic glands and lymphatic tissues generally. They pass into the lymphatics and thence into the blood-vessels.

*Plaques.*—These are also known as *blood-plates*, *blood-platelets*, and *hematoblasts*. They are circular or elliptical in shape, and smaller than the red corpuscles, but vary very much in size, from  $0.5\ \mu$  to  $5.5\ \mu$ , and are colorless. Their number is said to vary from 180,000 to more than 600,000.

Various theories have been propounded to explain their occurrence in blood. One of these is that they are not formed structures, but simply precipitates of nucleoproteid from the plasma. This theory is, we think, no longer held. There is little doubt that they are formed elements existing normally in the blood, although the theory of Hayem, who discovered them, that red corpuscles are formed from them, is no longer maintained.

Lilienfeld has obtained from them a nucleo-albumin, called by him *nucleohiston*, which is also found in the nuclei of the leukocytes, and it is believed by many that the blood-plates are nothing more than the nuclei of the polynucleated colorless corpuscles, which are set free when these corpuscles disintegrate, and that these plates also disintegrate, and are dissolved in the plasma. Their possible relation to the coagulation of the blood is discussed in connection with that subject (p. 294).

*Blood-plasma.*—The plasma or liquor sanguinis is yellowish in color and alkaline in reaction, having a specific gravity of 1027 to 1031. It contains the following ingredients: Water, inorganic salts, extractives, enzymes, proteids, and gases.

*Water and Inorganic Salts.*—Water exists in plasma to the approximate amount of 90 per cent., so that 10 per cent. consists of solids. Of these solids, about 0.85 per cent. are inorganic

salts; and of these, sodium chlorid is the most abundant, being present to the amount of 0.55 per cent. Sodium carbonate is present to the amount of 0.15 per cent.; and this salt is the principal cause of the alkalinity of the plasma, and gives it its power to absorb carbon dioxid. The salts of the plasma have not been exactly determined, but, according to Schmidt, the following table gives those that probably occur, with their percentages:

Potassium sulphate . . . . .	0.0281
Potassium chlorid . . . . .	0.0859
Sodium chlorid . . . . .	0.5546
Sodium phosphate . . . . .	0.0271
Sodium carbonate . . . . .	0.1582
Calcium phosphate . . . . .	0.0298
Magnesium phosphate . . . . .	0.0218

Calcium chlorid is probably also present, and traces of a fluorid have likewise been found.

*Extractives.*—These include *carbohydrates*, of which there are three: Glycogen, probably derived from the leukocytes; an animal gum; and dextrose. This last, we have seen, is always present in human blood to the amount of about 0.12 per cent., being much more abundant in portal blood during the digestion of carbohydrates. *Fat* is also a constituent of the plasma, the amount being increased by its absorption after a meal containing it. *Lecithin*, *cholesterin*, *lipochrome* (which gives the plasma its yellow color), *urea*, *uric acid*, *kreatin*, *kreatinin*, and occasionally *hippuric acid* are also present.

*Enzymes.*—Plasma contains at least five enzymes: (1) An *amylolytic*, which is, according to some authorities, produced by the red cells, while others attribute it to the leukocytes; (2) a *glycolytic*, causing a destruction of some of the dextrose in the blood. Although the existence of this enzyme is denied, there is strong evidence in favor of its existence. According to Spitzer, it exists in both red and white blood-cells and, indeed, in all tissue-cells. It acts only in the presence of oxygen; (3) a *lipolytic*, called *lipase*; (4) a *coagulating* thrombin or prothrombin, which causes coagulation of the blood under some circumstances (p. 293); (5) a *proteolytic*. The destruction of the exudate of pneumonia is attributed to this enzyme.

*Proteids.*—These are: (1) Serum-albumins,  $\alpha$ ,  $\beta$ , and  $\gamma$  (p. 108); (2) serum-globulin or paraglobulin (p. 110); (3) fibrinogen (p. 110); (4) nucleoproteid.

The total proteids in human plasma are 7.62 per cent., of which 3.10 per cent. are globulins, and 4.52 per cent. albumins.

The proteids of the plasma have been already discussed in dealing with this class of physiologic ingredients (p. 126), but one of them, fibrinogen, deserves special notice at this time because of its relation to the process of blood-coagulation.

*Fibrinogen.*—Although it is customary to speak of fibrinogen as if it was a simple substance, yet the fact that when it is dissolved in salt solution and heated to a temperature between 52° C. and 55° C. only a part of the proteid is coagulated, and that when the temperature reaches 65° C. another portion is thrown down, has led Hammarsten to regard it as made up of *fibrinogen proper*, which coagulates at the lower temperature, and a globulin, *fibrin-globulin*, which is coagulated at the higher temperature. It is believed that a nucleoproteid is also combined with these two proteids to make up what is commonly termed fibrinogen.

*Origin of Fibrinogen.*—Matthews, after a very elaborate study of the subject, reported in the *American Journal of Physiology*, concludes that the decomposing leukocytes of the blood, and chiefly those of the intestinal area, are the sources of the blood fibrinogen, and supports this opinion: “(1) By the increase in the per cent. of fibrinogen in all cases of prolonged leukocytosis accompanying suppuration; (2) by the increase in fibrinogen during leukocythemia; (3) by the increase in fibrinogen in pneumonia, erysipelas, acute rheumatism, peritonitis, and similar inflammatory conditions; (4) by the fact that fibrinogen is not simply transformed proteid of the food, as indicated by its continued formation during fasting, and its failure to increase during proteid digestion; (5) by the observation that neither the spleen, muscles, kidneys, pancreas, nor brain appears to be essential to its formation; (6) by the well-known fact that there is present in the cell-body of the leukocyte a substance which, by the action of a substance coming from the nucleus or arising in its neighborhood, is thrown into a fibrillar form closely resembling fibrin-fibrils, and like them contractile; (7) by the fact that the leukocytes are constantly going to pieces in the body, hence must be adding constantly to the proteid constituents of the blood; (8) by the close correspondence existing between the fibrinogen-content of the blood and the excretion of uric acid; and (9) by the fact that the intestine, which is rich in leukocytes, appears to be the chief source of the fibrinogen of the body.”

In this article Matthews makes the following statement, which is, to say the least, suggestive, although, of course, as yet not demonstrated: “If fibrinogen is derived from the leukocytes, as the preceding considerations indicate, and if Schmidt’s and Mörner’s observations on paraglobulin indicating its origin in the leukocyte prove well founded, the conclusion would seem obvious that the proteids of the blood are derived from the leukocytes. This would strongly confirm Hoffmeister’s view that the leukocytes are pre-eminently active in proteid absorption and assimilation. It would lead to the interesting conclusion that the organism lives on its leukocytes much as the egg-cells of some forms live on their follicle-cells. If this were so, it would explain (1) the true

function of the leukocytes and the elaborate arrangements for their production in the body ; (2) their congregation and great reproduction in the intestinal area during a proteid meal ; (3) the positive chemotaxis they exhibit toward the proteids, albumoses, and other products of digestion ; (4) the maintenance of the proteid constituents of the blood during fasting ; (5) the fate of the bodies of the leukocytes when they disintegrate ; (6) the fact that no products of digested proteids are found in the blood during proteid digestion. It would make the leukocyte, in fact, a storehouse of the surplus proteid food of the body, just as the liver-cell is a storehouse of surplus carbohydrate food."

*Nucleoproteid.*—In regard to this constituent of plasma, Schäfer says that it is doubtful if it exists in the plasma of circulating blood, and that beyond the fact of its appearing to be one of the essential factors in the formation of fibrin, very little is known about it. It is regarded as being derived from the leukocytes and plaques at the time the blood is withdrawn from the vessels. A small amount comes from the red corpuscles. The reasons for this belief as given by Schäfer are :

1. White blood-corpuscles and similar cells (lymph-cells, thymus-cells, etc.) always contain a considerable amount of nucleoproteid.

2. In plasma obtained by subsidence of the corpuscles there is most nucleoproteid in the lower layers, which contain most leukocytes ; and least in the upper, which contain very few.

3. Fluids which collect in the serous cavities of the body (pericardial fluid, hydrocele fluid, ascitic fluid) frequently contain no leukocytes. When this is the case they are also devoid of nucleoproteid and of the property of spontaneous coagulability, although they contain fibrinogen. Solutions of this nucleoproteid are coagulated at 65° C., and at 60°C., if free alkali is present, it is split into nuclein and a proteid. If soluble salts of lime are present, the nucleoproteid unites with the lime, and the product has the property of converting fibrinogen into fibrin, and is identical with *fibrin-ferment* or *thrombin* ; inasmuch as the nucleoproteid precedes and becomes changed into thrombin, it is termed *prothrombin*.

*Gases.*—The plasma contains oxygen and nitrogen in solution, and carbon anhydrid both in solution and also in combination as sodium carbonate and bicarbonate. The amount of oxygen in the plasma is very small : in the dog, 0.25 per cent.

**Coagulation of Blood.**—When blood is withdrawn from the circulation it undergoes coagulation, consisting in the production of a clot from which is subsequently expressed a fluid—the *serum*. The length of time required for coagulation varies in the blood of different animals. In human blood the change manifests itself in about two or three minutes. When the blood is withdrawn

from the vessel it is fluid, but at the end of two or three minutes its fluidity is so much diminished that it will not flow; this consistency increases until at the end of eight or ten minutes the entire quantity of blood becomes a mass resembling currant-jelly in color and consistency. This jelly-like mass becomes more and more consistent, squeezing out upon its surface a few drops of a straw-colored fluid—the serum. As the shrinking of this gelatinous mass—the *clot*—continues, it separates from the sides of the vessel in which the blood was received, and the serum is squeezed out on all sides, until at length there is a more or less solid clot floating in a considerable quantity of serum. The entire process requires from ten to forty-eight hours. When examined, the clot is found to be made up of fibrin and corpuscles, the red corpuscles giving to it the red color. The white corpuscles may at first be entangled in the meshes of the fibrin, but by virtue of their ameboid movement they soon escape into the serum. The serum has the same composition as the plasma minus the fibrinogen.

Although the corpuscles are denser than the plasma, still the difference is so slight and the process of coagulation so rapid that before they can settle they are entangled in the meshes of the fibrin as it forms, and thus become a part of the clot. If anything occurs to delay coagulation, the corpuscles settle, and the clot is then less red and more yellowish. This delay may be brought about by the addition of a 27 per cent. solution of magnesium sulphate or other neutral salt, the plasma being then termed *salted plasma*; it occurs also in inflammatory processes, and hence in the olden time, when venesection or “bleeding” was commonly practised, this *crusta phlogistica*, or “buffy coat,” was always looked for by the physician, and when it formed was considered as evidence that the bleeding was justifiable. That the physicians of that period were not always right in this judgment is now known, for a buffy coat will form in blood which is hydremic, a condition in which bleeding is contraindicated. In horses’ blood, which normally coagulates very slowly, this “buffy coat” always forms. It is simply the fibrin without the corpuscles, or at least without enough of them to give the red color which the clot usually possesses.

**Influences which Retard Coagulation.**—Coagulation is retarded by cold, by solutions of sodium or magnesium sulphate, by a diminished amount of oxygen, by an increased amount of carbon dioxid, by acids or alkalies, by egg-albumin, by oil, by a solution of albumose, and by extract of the head of the leech. It is well known that the blood drawn from the vessels by this animal does not coagulate within its body. It is supposed that its saliva contains an albumose which prevents clotting of the blood. Solutions of potassium or sodium oxalate also prevent coagulation. The explanation of this action is that the calcium which is required for the process is precipitated as calcium oxalate. Venous blood



coagulates more slowly than arterial, because of the lessened amount of oxygen and the increased amount of carbon dioxid. It is said that blood from the capillaries does not coagulate at all.

It is the prevalent opinion that menstrual blood does not clot; this, strictly speaking, is not true. If the blood was collected as it comes from the uterine vessels, it would doubtless coagulate as does other blood; but when it is mixed with the acid vaginal mucus its coagulation is then impeded. Then, too, during the menstrual period some of the blood undergoes clotting within the uterine cavity or in the vagina: that which escapes and which is regarded as menstrual blood is for the most part only serum, which, of course, does not coagulate.

**Influences which Hasten Coagulation.**—Heat hastens coagulation, as does agitation of the blood, as in whipping it with twigs or rods. In general, anything which tends to break down the leukocytes or plaques from which the nucleoproteid prothrombin is derived will cause the latter to be set free and favor coagulation.

**Causes of Coagulation.**—Perhaps no physiologic question has excited more controversy than that which deals with the cause of blood-coagulation. Normally, blood remains fluid within the blood-vessels, but within a few minutes after withdrawal it begins to undergo coagulation. What is the explanation?

It has been suggested that blood-coagulation is due to exposure to the air. It is true that contact with the air hastens coagulation, but that this is unnecessary to the process is shown by the fact that coagulation will take place under mercury when all air is excluded. Nor can it be due to the cooling the blood undergoes when it is exposed to the air, for, as already noted, cold retards coagulation, while heat aids it. It has also been suggested that the fluid condition of the blood in the circulation is due to its motion, and that it clots when it comes to a state of rest. But experiment shows that motion, such as the beating of blood with wires, hastens coagulation.

Experiments demonstrate that the fluidity of the blood is maintained only when the blood is in contact with the normal lining membrane of the blood-vessels: when this relation is interrupted, either by disease, or by death or injury of the membrane, or by withdrawal of the blood from the vessel, the fluidity ceases and the blood coagulates.

The property of coagulation possessed by blood is of great service in arresting hemorrhage. There are individuals in whom bleeding, which in most people would be only slight, amounts to a dangerous hemorrhage, often requiring surgical skill for its arrest, and in some instances being so uncontrollable, even by the most skilful treatment, that death results. Such persons are called *bleeders*, and on them surgeons hesitate to perform any operation, however trivial, the extraction of a tooth even being often

followed by an alarming loss of blood. This condition is spoken of as *hemophilia* or *hemorrhagic diathesis*. It is probable that in such cases the fibrinogen is very deficient.

**Theories of Blood-coagulation.**—From the many theories which have from time to time been advanced to explain this process, we shall select a few, each of which, although perhaps not now held in its entirety, still has elements in it which, combined with those of other theories, enter into the opinions held by the best authorities in regard to this as yet unsolved problem.

All explanations have as their basis the production of insoluble fibrin from soluble fibrinogen, but as to how this change comes about, or the agencies which cause it, there is great disagreement.

*Theory of Schmidt.*—The proteid now known as paraglobulin Schmidt termed *fibrinoplastin*, and in his theory this substance, under the influence of *fibrin-ferment*, which he later called *thrombin*, enters into combination with fibrinogen, the result being fibrin. This ferment was obtained by adding alcohol to blood-serum, and extracting it from the precipitate by water; it was destroyed by a temperature of 65° C., and had the power of coagulating a considerable amount of fibrinogen; it resembled, therefore, the ferments or enzymes, and was considered by Schmidt to belong to that class. He later considered that fibrinogen was derived from paraglobulin.

*Theory of Hammarsten.*—This experimenter demonstrated that paraglobulin takes no part in the process of coagulation, so that at the present time it does not enter as a factor into any of the theories of blood-coagulation. In Hammarsten's theory there are but two factors: fibrinogen and fibrin-ferment. The action of the ferment splits the fibrinogen into fibrin, which is insoluble, and *fibrin-globulin*, which remains in solution.

Schmidt, Hammarsten, Freund, Pagés, and others have shown that salts of calcium play a very important part in the coagulation process.

*Theory of Pekelharing.*—This theory supposes that the fibrin-ferment of Schmidt is composed of nucleo-albumin and calcium, and that the calcium leaves the nucleoproteid and unites with fibrinogen, the compound of the two being fibrin. The nucleo-albumin comes from the leukocytes and plaques, but does not exist in normal blood. As soon, however, as blood is shed, these cells disintegrate, with the result of setting free the nucleoproteid. As has already been stated, analyses show the same amount of lime in fibrinogen as in fibrin, so that this theory cannot be sustained.

*Theory of Liliensfeld.*—The originator of this theory attributes to the nucleoproteid the power of splitting the fibrinogen into a globulin and *thrombosin*, which latter unites with lime to form fibrin. He regards this power as due to the nucleic acid, and



states that acetic or any other weak acid will effect the same change in fibrinogen. This theory has also its weak points, and there is great doubt whether the clot is fibrin in any true sense of the term. Perhaps we can in no better way present to our readers the present status of this subject, which is at best unsatisfactory, than by giving the views of Schäfer in his *Text-book of Physiology*. The evidence seems fairly conclusive that three factors are essential to bring about coagulation of the blood. These are fibrinogen, the nucleoproteid prothrombin, and soluble lime salts, the two latter acting in combination, and forming Schmidt's fibrin-ferment or thrombin. In the normal blood-vessels the prothrombin and lime have not entered into the necessary combination or interaction which enables them to act as a ferment upon the fibrinogen. This nucleoproteid prothrombin cannot by itself act as a ferment, but must be exposed to the acting soluble lime salts; it does not follow, however, that the thrombin is a compound of the nucleoproteid and lime; nor is there any certainty as to just what the interaction is. The prothrombin doubtless comes from the leukocytes and plaques; but it is not necessary to suppose that they always undergo disintegration to produce it. It is also probable that the red corpuscles may contribute to this production of nucleoproteids, for they contain them, and the same is also true of the epithelial cells of the blood-vessels, which are doubtless composed of living protoplasm. Schäfer, in his text-book, sums up the evidence as to coagulation as follows:

1. That the coagulation of blood—*i. e.*, the transformation of fibrinogen into fibrin—requires for its consummation the interaction of a nucleoproteid (prothrombin) and soluble lime salts, and the consequent production of a ferment (thrombin).

2. That either nucleoproteid is not present in appreciable amount in the plasma of circulating blood, or that the interaction in question is prevented from occurring within the blood-vessels by some means at present not understood.

3. That the nucleoproteid (prothrombin) appears and the interaction occurs as soon as the blood is drawn and is allowed to come into contact with a foreign surface, the source of the nucleoproteid being in all probability mainly the leukocytes (and blood-platelets).

4. That under certain circumstances and conditions either the nucleoproteid does not appear in the plasma of drawn blood or it appears, but the interaction between it and lime salts is prevented or delayed.

5. That the nucleoproteid (prothrombin) appears in the plasma of *circulating blood* under certain conditions, being in all probability shed out from the white corpuscles and blood-platelets, or in some cases even from the red corpuscles; and that when shed out under these conditions from the corpuscles, or when artificially injected into the vessels, it tends at once to interact with the lime

salts of the plasma and to form fibrin-ferment (thrombin), intravascular coagulation being the result.

6. That under other conditions either the shedding out of nucleoproteid from the corpuscles or its interaction with the lime salts of the plasma may be altogether prevented and the blood rendered incoagulable, unless nucleoproteid is artificially added, or unless a modification of the conditions is introduced which will permit of the interaction of the nucleoproteid with lime to form ferment.

7. That the nucleoproteid (prothrombin) is incompetent, in the entire absence of lime salts, to promote the transformation of fibrinogen into fibrin; but, as a result of its interaction with lime salts, it becomes transformed into a ferment (thrombin), which, under suitable conditions of temperature, and the like, produces fibrin.

8. That either the place of nucleoproteid in coagulation may be taken by certain albumoses, such as those found in snake-venom, and by certain colloidal substances, such as those prepared by Grimaux; or that such substances may act by setting free nucleoproteid from the leukocytes and other elements in the blood, or from the cells of blood-vessels, and thus indirectly promote coagulation.

The colloidal substances referred to in paragraph 8 were three in number, and were artificially prepared by Grimaux, and presented many of the characteristics of proteids. They all gave the xanthoproteic reaction and in other ways resembled the proteid class. Thus when injected into the veins of animals, as the dog, cat, or guinea-pig, they caused intravascular coagulation, resembling in this respect nucleoproteid. It is suggested by Schäfer that they produce this effect not directly, but by setting free the nucleoproteid from the leukocytes, inasmuch as there is no disintegration of the red or white corpuscles, nor any apparent change in the epithelium of the vessels.

**Regeneration of Blood.**—One of the striking peculiarities of the blood is the rapidity with which it is renewed after hemorrhages. The blood constitutes about 7.7 per cent. of the weight of an adult; and it is estimated that a hemorrhage in which no more than 3 per cent. of the weight is lost will not be fatal, and that the plasma will be renewed in such cases within forty-eight hours, although it may require weeks for a renewal of the red corpuscles. In the treatment of severe hemorrhages it is now the practice to inject into the veins physiologic salt solution (p. 81). The rationale of this is stated by Howell to be that in normal blood the number of red corpuscles is greater than that necessary for a barely sufficient supply of oxygen, and that if after a hemorrhage the quantity of fluid in the vessels is increased, the circulation is made more rapid, and the remaining corpuscles are made

more effective as oxygen-carriers; this office is made still more effective by keeping the corpuscles from becoming stagnant in the capillary areas.

In proportion as intravenous transfusion of salt solution has come into favor for the treatment of hemorrhages, in a similar proportion has transfusion of blood been abandoned. From what has been said, it will readily be understood that in the withdrawal of blood from the vessels of a lower animal or man the conditions are most favorable for bringing about the destruction of leukocytes, and the consequent setting free of the nucleoproteid prothrombin. To throw this material into the circulation of a living animal is to invite coagulation within the vessels, a condition which is dangerous in the extreme, inasmuch as clots would be inevitably carried into the smaller arteries of the brain, causing *embolism*, and producing a fatal result.

It has also been demonstrated that the injection of the serum of the blood of some animals into the circulation of others, as that of man into the vascular system of a rabbit, destroys the red corpuscles. This is the *globulicidal* action of serum. Such a result might follow in the case of blood-transfusion, unless special care was taken to select an animal whose blood did not possess this action upon the blood of the animal on which the operation was to be performed.

**Hemolysis and Bacteriolysis.**—The fresh normal serum of the blood of a goat, an ox, a dog, etc., has the power to dissolve the red blood-cells of a rabbit or guinea-pig. This is described as the *normal globulicidal* property of serum. Such serum has also the power of dissolving many species of bacteria; this is its *bactericidal* property. Buchner attributed both of these to a substance existing in all normal serum, to which he gave the name *alexin*. In transfusing blood, therefore, in the treatment of hemorrhage, the danger of destroying the red blood-cells exists, in addition to the danger already mentioned. It should be said that Buchner's idea of alexin has been much modified by recent researches; it has been shown that the action of two substances is necessary to bring about hemolysis: an *inter-body* and a *complement*, the latter corresponding to Buchner's alexin. This was shown by Ehrlich and Morgenroth, who treated the blood of a guinea-pig with the serum of a dog, the complement existing in the guinea-pig and the inter-body in the dog.

These authorities carried their observations still further and found that normal goat serum would dissolve the red cells of both guinea-pigs and rabbits, and that in this serum there were two inter-bodies, one for the red cells of the rabbit and the other for those of the dog, and that there were also two complements. Ehrlich believes that there are many substances of similar character existing in the normal serum which have a hemolytic action.

Metchnikoff and Buchner regard the leukocytes as being the source of the complements or alexins, the former considering them as due to the breaking down of the corpuscles, the latter as true secretory products. Other authorities regard the connection between these complements and the leukocytes as not established. Wasserman believes the leukocytes to be one source, but not the only one, while Ehrlich and Morgenroth claim that the production of the complements is one of the functions of the liver.

**Hemagglutinins and Bacterial Agglutinins.**—The normal serum of the goat possesses also the power of *agglutinating* the red cells of the human being, the pigeon, and the rabbit—*i. e.*, causing them to adhere, forming clumps. The normal serum of a rabbit will agglutinate the bacilli of typhoid fever. This property is due to substances in the serum called *agglutinins*; those which agglutinate the red cells being distinguished as *hemagglutinins*. It is believed that there is a separate agglutinin for each species of blood-cells. The hemolysins and the agglutinins are not identical substances, for a serum can retain its agglutinating power after its hemolytic power is lost.

**Cytotoxins.**—If an animal is injected with white blood-cells, spermatozoa, etc., substances are produced in its serum which bring about a dissolving action in the cells used for the injection. These substances are termed *cytotoxins*. Thus, if the leukocytes of a rabbit are injected into a guinea-pig, the serum of the guinea-pig will dissolve the leukocytes of a rabbit; in this instance the cytotoxin is called *leukotoxin*. The action of such serum is believed to be due to interacting substances, as in the case of hemolysis. If spermatozoa are injected, a cytotoxin is produced, called *spermatoxin*.

**Precipitins.**—If, instead of injecting cells, the dissolved albuminous bodies of one species of animal are injected into another, there is a precipitation of albumin. Thus, if a rabbit is injected with the serum of a horse, and subsequently the rabbit serum is mixed with that of a horse, the mixture becomes cloudy, owing to the precipitation of the horse's albumin. The substances which produce this precipitation are termed *precipitins*.

A practical application has been made of the knowledge obtained by this research into the nature of precipitins in the identification of blood-stains. For the details of the method the reader is referred to text-books treating of the subject. Ewing states that the reaction does not fail with very old specimens of blood, although it becomes less distinct the older the specimen. Ziemke obtained a cloudiness in three hours from a blood-stain twenty-five years old; from blood mixed with earth three years old; from decomposed blood; and from human blood highly diluted with six other kinds of blood. A solution of iron rust gave no reaction. Uhlenmuth secured positive results with blood of a three months' decomposed cadaver. Stern obtained the characteristic reaction in solutions of 1 of serum to 50,000 of blood. Ewing

concludes his discussion of the subject, in his *Clinical Pathology of the Blood*, as follows : “ From the foregoing discussion it is evident that full medicolegal requirements for the positive identification of blood-stains may be met, under some conditions, by the biologic test. These conditions are the positive proof by the hemin test that the material is blood, and the occurrence of a flocculent precipitate appearing within one to three hours in the suspected specimen and in no other of the controls when a potent serum is added in proportion of 1 : 50 of blood.

“ While these conditions can usually be secured when dealing with fresh blood in considerable quantities, in the writer’s opinion and experience the material submitted for medicolegal examination is more apt to be old, scanty, and impure, and the difficulty of securing a fully satisfactory test by this method is thereby greatly increased. With such material one has often to be content with faint turbidities instead of flocculent precipitates, and in such cases it would appear, as Stoenesco maintains, that a guarded opinion be given and the claim made only that the specimen is probably human blood. It should be added that an absolutely faultless technic is required, and that this can be obtained only after considerable experience.”

LYMPH.

Lymph is an alkaline fluid which is derived from the blood, and while, generally speaking, its constituents are the same as those of the plasma, still these differ in amount to a considerable degree ; nor is the lymph obtained from all parts of the body uniform in composition.

**Chemical Composition of Lymph.**—The following analysis is of lymph obtained from a case of fistula of the thoracic duct in man, and is reported by Munk and Rosenstein. In 100 parts of lymph there are :

Total solids . . . . .	3.7	to 5.5
Proteids . . . . .	3.4	“ 4.1
Substances soluble in ether . . . . .	0.046	“ 0.13
Sugar (dextrose) . . . . .	0.1	
Salts . . . . .	0.8	“ 0.9

In another specimen the inorganic constituents were found by Hensler and Dänhardt to be :

NaCl . . . . .	0.614	MgO	} . . . . . traces
Na <sub>2</sub> O . . . . .	0.057	Fe <sub>2</sub> O <sub>3</sub>	
K <sub>2</sub> O . . . . .	0.049	So <sub>3</sub>	
CaO . . . . .	0.013	P <sub>2</sub> O <sub>5</sub>	} . . . . . 0.033
Co <sub>2</sub> . . . . .	0.0815		

From lymph only 0.1 per cent. of fibrinogen can be obtained, while from plasma the amount obtainable is 0.4 per cent. Besides fibrinogen, paraglobulin and serum-albumin are also present.

Lymph coagulates more slowly than the blood, and the clot is less firm. Urea is present to a greater amount than in plasma.

**Histologic Composition of Lymph.**—Examined under the microscope lymph is found to contain colorless cells, *lymphocytes*, which pass into the blood with the lymph and there become leukocytes (p. 291). Fat-globules are also found, especially after a meal, and in the lymph from the thoracic duct.

**Origin of Lymph.**—While there is no doubt that the source of the lymph is the blood, still there is a difference of opinion as to the manner in which it escapes from the blood-vessels.

**Theory of Ludwig.**—Ludwig believed that the pressure of the blood in the capillaries was sufficient to cause the plasma to filter through their walls, thus forming the lymph. He also believed that diffusion played a part in lymph-formation. He expressed his views as follows: "The blood which is contained in the vessels must always tend to equalize its pressure and its chemical constitution with those of the extravascular fluids, which are only separated from it by the porous blood-vessel walls. If, for example, the quantity of blood in the vessels has increased, the mean blood-pressure is also increased, and at once a portion of the blood is driven out into the tissues by a mere process of filtration. The same result is brought about when the constitution of the blood is altered by the absorption of food or by increased excretion by the kidneys, blood, or skin, or when the composition of the tissue-fluids is altered in consequence of increased metabolic changes taking place in the tissues. In the latter case the changes brought about in the lymph are effected by processes of diffusion." This theory of Ludwig may, therefore, be termed that of *filtration* and *diffusion*.

**Theory of Heidenhain.**—This experimenter studied the subject of lymph-formation by examining the flow from the thoracic duct. He found that if the thoracic aorta was obstructed, there would follow a fall of arterial blood-pressure below the obstruction, and yet there was no diminution in the flow of lymph in the thoracic duct, and in some cases it was increased. If lymph was formed by filtration from the blood, a diminution of blood-pressure should have been followed by a corresponding lessening of lymph-production. Other experiments demonstrated that the flow of lymph might be increased without correspondingly increasing the blood-pressure. He also found that if commercial peptone and some other substances were injected into the blood-circulation, the amount and concentration of the lymph would be increased, although blood-pressure might be reduced; also that if concentrated solutions of sodium chlorid or sugar were injected, the flow of lymph would be increased and its concentration diminished. If blood-pressure was increased, it was so but slightly. Heidenhain terms substances having the power of increasing the flow of lymph *lymphagogues*. These experiments demonstrated that the lymph



may contain more of injected substances than the blood-plasma, while at the same time there is no increase in blood-pressure. From these experiments Heidenhain formed the opinion that filtration and diffusion cannot explain all the facts connected with the formation of lymph, but that it is to be attributed to a selective power of the endothelial cells of the walls of the capillaries, and that lymphagogues act by stimulating these cells.

This subject has been investigated by Starling, who finds many reasons for upholding the theory of Ludwig as against that of Heidenhain. For a full discussion of the subject we must refer our readers to Schäfer's *Physiology*, but it will not be out of place to quote Starling's conclusions. He says:

"Thus a renewed investigation of the facts discussed by Heidenhain has shown that they are not irreconcilable with the filtration hypothesis, but rather serve to support it. At the same time they prove the extreme importance of the factor upon which so much stress was laid by Cohnheim, namely, the nature of the filtering-membrane. In fact, we may say that the formation of lymph and its composition, apart from the changes brought about by diffusion and osmosis between it and the tissues it bathes, depend entirely upon two factors: 1. The permeability of the vessel-wall. 2. The intracapillary blood-pressure.

"So far as our experimental data go, we have no sufficient evidence to conclude that the endothelial cells of the capillary walls take any active part in the formation of lymph. It seems rather that the vital activities of these cells are devoted entirely to maintaining their integrity as a filtering-membrane, differing in permeability according to the region of the body in which they may be situated. Any injury, whether from within or without, leads to a failure of this their one function, and therefore to an increased permeability, with the production of an increased flow of a more concentrated lymph.

"We have no evidence that the nervous system has any influence on the production of lymph in any part, except an indirect one by altering the capillary pressures in the part through the intermediation of vasoconstrictor or dilator fibers. This action is better marked in situations where the capillaries are normally very permeable or where the permeability has been increased by local injury to the vessels, or by the circulation of poisons in the blood-stream."

The lymph-corpuscles enter the lymph as it passes through the lymphatic glands or other lymphoid tissue, such as the tonsils and the thymus gland, and become constituents of the lymph.

**Office of the Lymph.**—The lymph after it passes out from the blood-vessels bathes the tissues, and is one of their sources of nutrition, but not the only one, for there is abundant evidence that tissues may receive their nutritive supply directly from the blood and pass into that fluid their waste-products. This muscles will

## PLATE II.

*A*, aorta, with left vagus and phrenic nerves crossing its transverse arch; *B*, root of pulmonary artery; *C*, right ventricle; *D*, right auricle; *E*, vena cava superior, with right phrenic nerve on its outer border, *F, F*, right and left lungs collapsed, and turned outward to show the heart's outline; *G*, inferior vena cava; *H*, celiac axis, dividing into the gastric, splenic, and hepatic arteries (MacLise).





do, while at the time no lymph is flowing in the lymphatic vessels of the part. When lymph accumulates, whether in a serous cavity or in the cellular tissue beneath the skin, it constitutes *dropsy* or *edema*.

The lymph is collected by the lymphatic vessels and ultimately reaches the blood-circulation again (p. 330).

CHYLE.

The term *chyle* is applied to that portion of the lymph which comes from the small intestine during the period of digestion. The tissues of this portion of the body are, like all others, bathed in lymph; but during digestion such products as enter the lacteals change its composition to a considerable extent, and the fat gives to it a milky appearance. The following is an analysis of chyle taken from a fistula of the thoracic duct in man (Paton):

Water . . . . .	95.34
Proteids . . . . .	1.37
Fats . . . . .	2.40
Cholesterin . . . . .	0.06
Lecithin . . . . .	0.03
Inorganic constituents . . . . .	0.56

CIRCULATORY SYSTEM.

The blood in carrying nutrition to, and in carrying waste products from, the tissues passes through the entire circulatory system, and this constitutes the *circulation of the blood*. Before studying this process in detail it is essential to have a knowledge of the organs concerned in carrying it on—*i. e.*, the circulatory organs. These are (1) the *heart*, (2) the *arteries*, (3) the *capillaries*, and (4) the *veins*.

THE HEART.

The heart, together with the great blood-vessels at its base, is enclosed in the **pericardium**, a fibroserous membrane having an external fibrous and an internal serous layer. The serous layer not only lines the inner surface of the sac, forming the *parietal portion*, but it also covers the heart itself; this portion is the *visceral portion* or **epicardium**; its structure is similar to that of other serous membranes, being composed of connective tissue and elastic fibers, beneath which are the blood-vessels, nerves, and lymphatics of the heart.

The **myocardium**, or muscular structure of the heart, is composed of transversely striated muscular fiber-cells, each containing a single nucleus. They differ from voluntary muscle in possessing no sarcolemma, in branching and uniting with adjoining cells, and in having their striæ less pronounced (p. 61).

The **endocardium**, which lines the heart and takes part in the formation of the valves, resembles the epicardium in structure, and is covered by endothelium.

The heart (Figs. 157, 158) is a hollow muscular organ whose functions consist in acting as a reservoir and also as a pump, the *auricles* being the reservoir and the *ventricles* being the pump (Plate 2). It is about 12.5 cm. long, 8 cm. wide in its widest part, and 6.3 cm. thick at its thickest part; its weight is about 300 grams in the adult. It has a conical form, its *base* being above and to the right, and its *apex* below and to the left. It is divided longitudinally by a partition or *septum* into a right and a left half, which are sometimes denominated the right heart and the left heart. Each half is composed of an auricle and a ventricle; thus there are four cavities—the right auricle, the right ventricle, the left auricle, and the left ventricle.

The **right auricle** (Fig. 157) is somewhat larger than the left, and has the thinnest walls of the four cavities, measuring about 2 mm. in thickness. Discharging into this cavity are the superior and inferior *venæ cavae*, at the mouths of which there are no valves. Within the cavity is the *Eustachian valve*, which will further be described when discussing the fetal circulation. This valve is situated between the opening of the inferior vena cava and the auriculoventricular orifice.

FIG. 157. —Interior of right auricle and ventricle, exposed by the removal of a part of their walls: 1, superior vena cava; 2, inferior vena cava; 2', hepatic veins; 3, 3', 3'', inner wall of right auricle; 4, 4', cavity of right ventricle; 4'', papillary muscle; 5, 5', 5'', flaps of tricuspid valve; 6, pulmonary artery, in the wall of which a window has been cut; 7, on aorta near the ductus arteriosus; 8, 9, aorta and its branches; 10, 11, left auricle and ventricle (Allen Thomson).

The **right ventricle** (Fig. 157) has walls whose thickness

is greater than that of either auricle, but less than that of the left ventricle. The cavity of the right ventricle communicates with that of the right auricle by the right auriculoventricular orifice, at which is situated the tricuspid valve. It ordinarily contains, when filled, 87 grams of blood (p. 314). Connected with this ventricle is the pulmonary artery, at whose point of junction with the ventricle is the pulmonary orifice, at which is situated the pulmonary valve.

The **left auricle** (Fig. 158) is not so large as the right, but its walls are thicker. Discharging into it are the two right and the

two left pulmonary veins, the former coming from the right and the latter from the left lung. The left veins sometimes join, and have but a single opening, in which case there would, of course, be but three openings instead of four. At these openings there are no valves.

The **left ventricle** (Fig. 158) is by far the most powerful of the four subdivisions of the heart. Its walls are three times as thick as those of the right ventricle. The capacity of its cavity is the same as that of the right. The left auricle and ventricle communicate by the left auriculoventricular orifice, at which is situated the mitral valve. Connected with this ventricle is the aorta, the opening of communication being the aortic orifice, at which is situated the aortic valve.

On the inner surface of the ventricles the muscular tissue projects, and forms the *columnæ carneæ*, or fleshy columns; some of these are ridges only, while others are attached at both ends, but are unattached in the middle, while still others project into the cavity and are attached at one extremity only; the latter are the *musculi papillares*, or papillary muscles.

**Cardiac Valves.**—There are four sets of valves in the heart: (1) The tricuspid; (2) the pulmonary; (3) the mitral; and (4) the aortic. The pulmonary and aortic valves are sometimes spoken of as the semilunar valves.

The **tricuspid valve** (Fig. 159) is situated at the right auriculoventricular orifice, and, as its name implies, consists of three cusps or segments. The bases of these cusps are attached to the opening, while the other edges are free, and to them are attached the *chordæ tendinæ*, or tendinous cords, the other ends being connected with the free extremities of the *musculi papillares* to which reference has been made. This valve, when shut, closes the right auriculoventricular orifice; when open the segments are in the cavity of the right ventricle. The tendinous cords prevent these segments from passing into the cavity of the auricle at the time of the valve's closure, while the papillary muscles by their shortening keep the cords taut at the time of the ventricle's contraction, as will be seen later.

FIG. 158.—Left auricle and ventricle, opened and part of their walls removed to show their cavities; 1, right pulmonary vein cut short; 1', cavity of left auricle; 3, 3'', thick wall of left ventricle; 4, portion of the same with papillary muscle attached; 5, the other papillary muscles; 6, 6', the segments of the mitral valve; 7, the figure in aorta is placed over the semilunar valves; 8, pulmonary artery; 10, aorta and its branches (Allen Thomson).

The **pulmonary valve** is sometimes spoken of as the *pulmonary semilunar valve* or valves. It is composed of three, occasionally two, segments, and is situated at the beginning of the pulmonary artery. These segments are attached at their bases to the wall of the artery, and on the free edge of each is a projection, the *corpus Arantii*. When the valve is open the segments lie against the walls of the artery; when it is shut they are in contact, and thus close the orifice of the pulmonary artery.

FIG. 159.—Orifice of the heart, seen from above, both the auricles and the great vessels being removed: PA, pulmonary artery and its semilunar valves; AO, aorta and its valves; RAV, tricuspid, and LAV, bicuspid valves; MV, segments of mitral valve; LV, segments of tricuspid valve (Huxley).

The **mitral valve** is sometimes described as the bicuspid, because it consists of two cusps. The attachments of the segments, the presence of chordæ, and the other anatomic points referred to in speaking of the tricuspid valve are to be seen in connection with the mitral. It closes the auriculo-ventricular orifice.

The **aortic valve** resembles in all essential particulars the pulmonary; it likewise is sometimes called the *semilunar valve*, and closes the aortic orifice.

The *ventricular septum* is the partition between the right and left ventricles. It is closed at all periods of life. The *auricular septum*, between the auricles, is closed from the tenth day after birth; prior to this time and during fetal life it has an opening, the *foramen ovale*, which serves as a means of communication between the right and the left auricles.

**Structure of the Valves.**—The valves consist of reduplications of endocardium, between which is fibrous tissue.

### THE ARTERIES.

Arteries are composed of three coats: (1) An internal, *tunica intima*; (2) a middle, *tunica media*; and (3) an external, *tunica adventitia*.

The **tunica intima** consists of a layer of pavement-epithelium (Fig. 160), the cells being polygonal, oval, or fusiform, termed *endothelium*, and of a network of elastic fibers or a *fenestrated membrane* (Fig. 161). Between these two layers is a subepithelial layer consisting of connective tissue.

The **tunica media** has a special physiologic interest. In the large arteries—that is, those larger than the carotids—this coat is principally yellow elastic tissue, only about one-fourth being muscular tissue. Vessels of this size are therefore characterized by

their elasticity. In the arteries of medium size—that is, those between the carotids and those having a diameter of about 2 mm.—the amount of muscular tissue is very much increased, while the

Endothelium of the  
intima.  
Intima.  
Media.

Adventitia with  
non-striated mus-  
cle-fibers in cross-  
section.

FIG. 160.—Section through human artery, one of the smaller of the medium-sized;  $\times 640$  (Böhm and Davidoff).

elastic tissue is also well represented. Such arteries possess, therefore, both contractility and elasticity. In the small arteries—that is, those less than 2 mm. in diameter—the external coat gradually

Intima.  
Elastica in-  
terna.

Endothelium of  
the intima.

Media.

Fenestrated  
elastic mem-  
brane.

Elastica ex-  
terna.  
Inner layer of  
adventitia.

Outer layer of  
adventitia.

Vasa vasorum.

FIG. 161.—Cross-section of the human carotid artery;  $\times 150$  (Böhm and Davidoff).

disappears until in the arterioles there remains only muscular tissue, representing the middle coat and the internal coat. These vessels are endowed with the property of contractility.

The **tunica adventitia** consists of bundles of white connective tissue and elastic fibers, and gives to the artery its strength. This coat merges with the sheath of the artery, which is composed of fibro-areolar tissue, and in this are the blood-vessels which supply the arteries, the *vasa vasorum*.

### THE CAPILLARIES.

The capillaries are minute vessels, having in general a diameter of  $12\ \mu$ , though this differs very considerably in the different organs of the body. They are smallest in the brain and intestinal mucous membrane, and largest in the skin and bone-marrow, where they have a diameter of about  $20\ \mu$ .

Their arrangement is also subject to great variation; thus in the lungs and mucous membranes they form rounded meshes, while in muscles and nerves the form of the mesh is elongated. In some organs they are very close together, as in the lungs, while elsewhere they are separated to a considerable extent, as, for instance, in the external coats of arteries. In general, where an organ is active, as is the kidney, there the number of capillaries is the

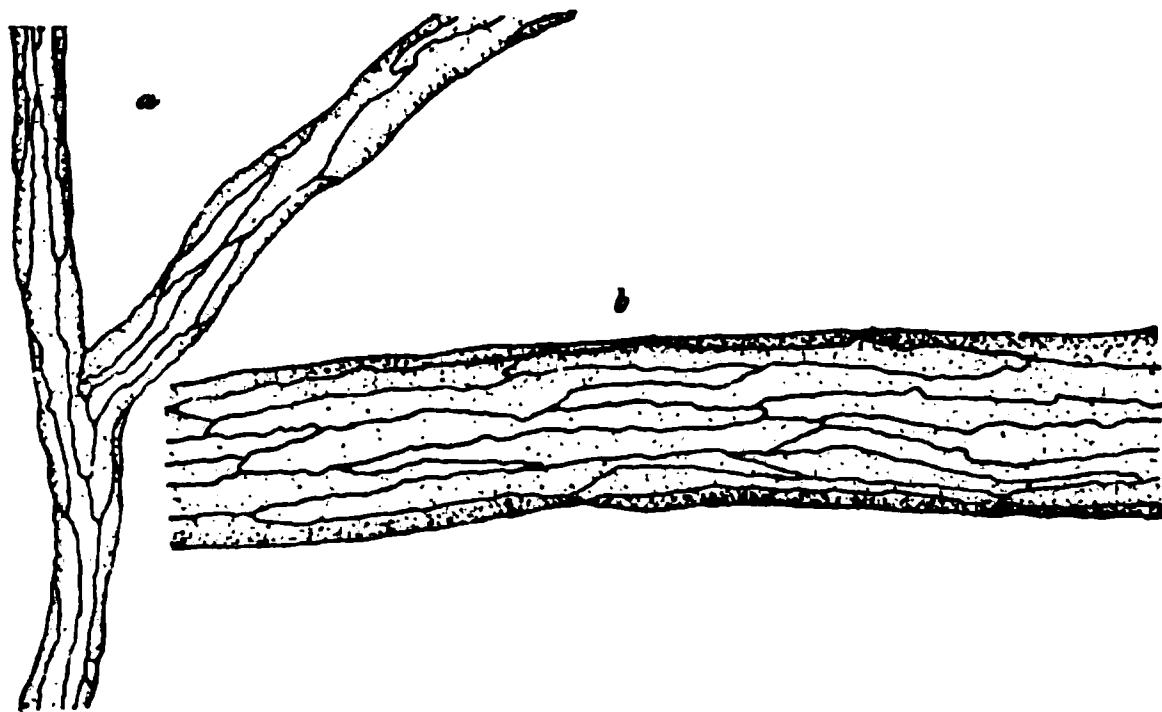


FIG. 162.—Endothelial cells of capillary (a) and precapillary (b) from the mesentery of a rabbit; stained in silver nitrate (Huber).

greatest; and where it is inactive, as is the case with bone, the capillaries are correspondingly lacking.

The walls of the capillaries consist of endothelial cells joined edge to edge by a cement-material.

From a physiologic standpoint this portion of the circulatory apparatus is the most important, as all the changes between the blood and the tissues take place while the blood is passing through the capillaries.

### THE VEINS.

The structure of the veins is in many respects similar to that of the arteries. They are likewise composed of three coats, but

the middle coat is the thinnest—so much so, indeed, that, while the arteries when cut remain patulous, the veins collapse. This coat contains both elastic and fibrous tissue: the former gives the vessels some elasticity, while to the latter is attributable the greater strength of the veins as compared with the arteries. The greater thickness of the arterial wall would seem calculated to make these vessels the stronger, but, although possessed of thin walls, still the white fibrous tissue which aids in their formation gives the veins greater resisting power. Valves are to be found in most of the veins, but are absent in those whose diameter is less than 2 mm.; also from the vena cava, hepatic, portal, renal, uterine, ovarian, cerebral, spinal, pulmonary, and umbilical veins. The valves are so arranged that they permit the blood to flow in the direction of the heart, but prevent its flow in the opposite direction. They consist of a reduplication of the internal coat, together with connective and elastic tissue to give them strength. Like the arteries, they are supplied with vasa vasorum to nourish their walls.

#### CIRCULATION OF THE BLOOD.

The course of the blood, starting from any point, may be traced through the circulatory apparatus. The circulation from the right ventricle through the lungs and back to the left side of the heart is the *lesser* or *pulmonary* circulation; that from the left ventricle through the rest of the body other than the lungs and back to the right side of the heart is the *greater* or *systemic* circulation. Beginning with the right auricle, the blood flows into this cavity from the venæ cavæ (inferior and superior); thence through the right auriculoventricular orifice into the right ventricle; thence into and through the pulmonary artery to the lungs; thence by the pulmonary veins into the left auricle; thence through the left auriculoventricular orifice into the left ventricle; thence into and through the aorta and the arterial system to the capillaries; through these vessels to the veins, by which, through the venæ cavæ, it returns to the right auricle, the place of beginning.

**Cardiac Movements.**—If the heart is exposed in a living animal—a dog, for example—it will be seen that the ventricles are at one time in motion and at another time at rest. Each period of motion and rest constitutes a *pulsation* or a *cardiac cycle*, and these pulsations recur very rapidly, so much so that the intervals are recognized with difficulty. These different states of the heart are better detected by the sense of touch than by that of sight. If the ventricles are grasped by the hand, it will be found that, corresponding with the resting stage, the muscular tissue composing them is soft and flaccid, while during the active stage it is hard and resisting. If these movements are studied still more carefully and analyzed, it will be found that the beginning of the



cardiac movement, which immediately follows the stage of rest, occurs in the auricles, in the region of the openings of the venæ cavæ on the right side, and of the pulmonary veins on the left; that this movement is propagated along the auricles in the direction of the ventricles; and that by the time it has reached the auriculoventricular orifices it has ceased at the orifices of the veins, and the muscular tissue in this region has begun to relax. It is to be noted that the auricles act synchronously, so that whatever is the condition of one auricle as to relaxation or contraction of its muscular tissue, the same condition exists in the other. This contraction of the auricles is spoken of as the *auricular systole*, and has something of a peristaltic character, which has already been studied in connection with the stomach and small intestine, although differing materially in that it is much more rapid.

Up to this time the ventricles are relaxed, or in a condition of diastole; but as soon as the auricular contraction reaches the ventricles these organs take it up, although in a different manner. For, while in the auricles one portion is contracting while another is relaxing, in the ventricles the whole mass of muscle contracts at once with a degree of suddenness and vigor which might be expected of so large a mass of striped muscular tissue. This contraction is the *ventricular systole*, and while it is taking place the auricles are relaxing throughout; this relaxation constitutes the *auricular diastole*. Thus the auricular systole and ventricular diastole, and the auricular diastole and ventricular systole, are respectively synchronous. Immediately after the systole of the ventricles these structures relax, and for a brief period the whole heart, both auricles and both ventricles, is in a state of relaxation; this is the *pause* of the heart. The work performed by the ventricles is so much more important than that of the auricles that when the terms *systole* and *diastole* are used, reference is always had to these states of the ventricles, the auricles being practically ignored. To designate the corresponding states of the auricles it is always necessary to speak of the auricular systole and diastole.

**Cardiograph.**—The cardiograph is an instrument for recording the movements of the heart, the record itself being a *cardiogram*. The form most used is that of Marey. It consists of a metal box, over the mouth of which an elastic membrane is stretched, to which a knob is attached (Fig. 163). This knob, in another form of this instrument, is attached to a spring (Fig. 164). This box or *tympanum* is in connection with another box, the *recording tambour*, by means of a tube, and upon the elastic membrane of this rests a lever. The first tambour is so fixed in place against the chest wall as to bring the knob over the point where the cardiac impulse is felt, and the movement of the knob is com-

municated to the membrane, sending a wave of air through the tube and causing the lever to move at every impulse; the point of the lever makes its record on a revolving drum or *kymograph*, covered with smoked paper (Fig. 166). This may be varnished with shellac for preservation. Fig. 164 shows a cardiogram taken in this way.

The same instrument in a modified form is used to obtain a record of the *endocardiac pressure*. In this case India-rubber bags communicating with the recording tambours are introduced through the jugular vein into the cavities of the right auricle and ventricle. This method is of service only in an animal with large vessels, such as the horse.

**Movements of Blood during Systole and Diastole.**—Before considering other movements of the heart it will be well to study the course of the blood while contraction and relaxation of the muscular tissue of this organ are taking place.

The venous blood, returning from the head and upper extremities by the superior or descending vena cava, and from the portion of the body below the heart by the inferior or ascending vena

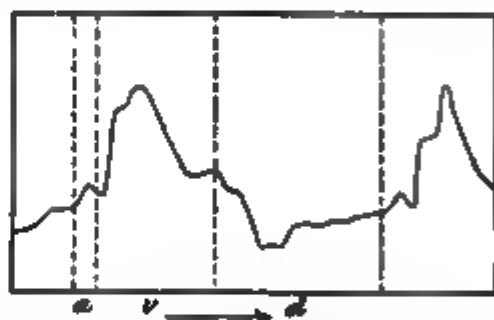


FIG. 163.—Diagram of Marey's cardiograph: A, knob attached to flexible membrane tied over end of metal box; the knob is placed over the apex-beat; C, folded edge of membrane; B is the tube communicating with a recording tambour.

FIG. 164.—Cardiogram taken with Marey's cardiograph: a, auricular systole; v, ventricular systole; d, diastole. The arrow shows the direction in which the tracing is to be read (Stewart).

cava, flows into and through the right auricle, passing into the right ventricle through the right auriculoventricular orifice. The tricuspid valve at this time is open, and offers no obstacle to the passage of the blood. Blood is also at the same time flowing into the left auricle and ventricle from the lungs. More blood enters the auricles than can at once pass out into the ventricles; consequently some blood accumulates in, and gradually fills, the auricles, although at the same time as much blood is flowing into the ventricles as the auriculoventricular orifices will permit to pass, nearly filling these cavities, and floating up the segments of the mitral and tricuspid valves until they are nearly closed. This is the condition at the end of the pause. At this moment begins the auricular systole. Near the ends of the veins which discharge

into the auricles—that is, the *venæ cavæ* and pulmonary veins—are muscular fibers; these fibers contract, diminishing the size of the orifices of the veins, thus taking the place of valves, and partially preventing a back-flow of blood into these vessels. Then the muscular fibers of the auricles in contiguity with these fibers contract, the movement spreading to the adjoining fibers until the wave of contraction has reached the ventricles. This auricular contraction forces more blood into the ventricles, and as the fibers relax the blood enters the auricles again from the veins. It will thus be seen that the interval of time during which the venous flow is arrested is the briefest possible. The principal office of the auricles is to serve as reservoirs to supply the ventricles; the work they do in completing the filling of these cavities is comparatively unimportant.

The auricular systole is followed by the systole of the ventricles. These cavities are at this time filled with blood, and the auriculoventricular valves are nearly closed, the segments having been raised up by the blood from the auricles. The ventricles, as has been stated, contract *en masse*, and the blood which they contain is compressed with great force. Under the pressure it tends to escape from the ventricles through all outlets—on the right side through the right auriculoventricular orifice back into the right auricle, and through the pulmonary orifice into the pulmonary artery; on the left side through the left auriculoventricular orifice into the left auricle, and through the aortic orifice into the aorta. The pressure of the blood instantly closes the tricuspid valve, and thus prevents the blood from going back into the right auricle. The same force closes the mitral valve, and regurgitation of blood into the left auricle is made impossible. The pulmonary and aortic valves, as has been stated, open from the ventricles into the arteries. At the beginning of the ventricular systole these valves are closed, but when systole occurs the pressure of the blood forces them open, and the contents of the ventricles, 70 c.c. for each, are propelled into the pulmonary artery and the aorta respectively. Authorities differ as to the amount of blood which is expelled from the ventricle at each pulsation, and which is termed the *pulse volume*; some place it as low as 50 c.c., and others as high as 190 c.c. Stewart gives it as his opinion that the average amount of blood thrown out by each ventricle at each beat is not more than 70 c.c. or 80 c.c. (87 grams). This agrees closely with Tigerstedt's calculation, which places the amount at 69 c.c. If the average amount is 70 c.c., the whole blood of the body would pass through the heart in about a minute. In accomplishing this the ventricles have to overcome the pressure which the blood already in the arteries is exerting on the other side of the valves to keep them closed. This pressure in the arteries is equal to a column of mercury, approximately, 150 mm. high, and in the pulmonary

artery is one-third as much. The amount of work done by the ventricles daily in thus forcing blood into the arteries is equal to that which is performed by an individual weighing 75 kilograms in climbing a mountain 806 meters in height.

As soon as the ventricles cease their contraction the pressure of the blood in the arteries closes the pulmonary and aortic valves, the ventricles begin their diastole, and the pause of the heart commences. As it was at this point that the consideration of the changes which take place was begun, the study of a cardiac cycle, cardiac period, or heart-beat is now completed. If the time occupied by such a period is divided into one hundred parts, it will be found that the auricular systole lasts during nine of the parts, the ventricular systole during thirty, and the pause during sixty-one; or, in other words, the heart is at rest six-tenths and at work four-tenths of the time.

**Shortening of the Heart.**—At the time of the systole of the heart (ventricular systole) the organ becomes shorter, yet the apex does not change its place, for the lengthening of the aorta which occurs compensates for the shortening, so that while the apex and base approximate the whole heart is lowered, the result being to keep the apex in its original position with reference to the chest wall.

**Cardiac Impulse.**—The situation of the heart in the thoracic cavity is such that its apex is against the chest wall at the fifth intercostal space, the space between the fifth and sixth ribs, and about 3 cm. below and 1 cm. within the left nipple. The apex of the heart is the extreme point of the left ventricle. If the finger is placed in this region during the ventricular systole, there will be felt a *tap* as if something was gently striking it. This tap is known as the *apex-beat*. It is so called because it was formerly supposed that during the systole the heart was raised up and carried forward so as to cause the apex to strike against the chest wall and thus produce the sensation. A more careful study of the changes which the heart undergoes during systole has, however, demonstrated that the apex of the heart is always in contact with the chest wall, and that this supposed striking does not take place. Indeed, the tap is not due to the apex at all. The term *apex-beat* is a misnomer: it should rather be called *cardiac impulse*, the sensation being produced by the anterior surface of the contracting ventricles swelling out and hardening. The location at which this impulse is felt most pronouncedly is not over the apex, but higher up. If a long needle was to be introduced deeply here, it would penetrate the left ventricle at a point where the middle and lower thirds unite. The cardiac impulse is not always, even in health, detected at the same place: it changes somewhat with respiration and also with changes in the position of the body.

**Papillary Muscles.**—It has been stated that during the ventricular systole the heart shortens. It is manifest that unless some provision was made this change in the shape of the heart would permit of regurgitation of the blood into the auricles, and thus would result a damming back of the blood in the venæ cavæ and pulmonary veins; for if the chordæ tendinæ were of just the right length at the beginning of the ventricular systole to keep the segments of the mitral and tricuspid valves so exactly in place as not to permit a leakage, then when the ventricles shortened these cords would be too long, and would permit the segments to enter the cavity of the auricles and there separate, leaving a considerable gap through which the blood could pass. That this does not occur is due to the papillary muscles. As the ventricles shorten, these structures contract sufficiently to take up the slack in the cords, and keep them just long enough to maintain the proper approximation of the segments of the valves.

**Cardiac Sounds.**—When the ear is placed against the chest wall in the region of the heart two sounds are heard during each cardiac period. The first of these sounds is heard loudest—that is, at its maximum of intensity—over the apex, and is by some writers called the *apex-sound*. For the reason that it is the first sound heard after the pause it is called the *first sound*, and because it occurs at the beginning of the systole of the heart (ventricular systole) it is called the *systolic sound*. The second sound is heard loudest over the base of the heart, and is therefore sometimes described as the *basal sound*; inasmuch as it occurs during the diastole, it has received the name of the *diastolic sound*. More commonly, however, it is spoken of as the *second sound*.

**Characteristics of the Cardiac Sounds.**—The first sound, as compared with the second, is lower in pitch and longer in duration, and has been likened to the sound of the word *lūbb*. The second sound is higher in pitch and shorter in duration than the first, and has been likened to the sound of *dūp*. These sounds occur successively, without any interval between them; in the pause which follows no sound is heard.

**Causes of the Cardiac Sounds.**—The cause of the second sound is undoubtedly the closure of the aortic and pulmonary valves. This has been demonstrated by hooking back the segments of the valves, when the sound disappears, to reappear when the segments are set free. The causation of the first sound is not so simple; indeed, authorities are not at one on this point. The closure of the mitral and tricuspid valves contributes something to it, but the closing of the valves is not the sole factor, for in a heart in which there is no blood the sound may still be heard, although modified, and in such a heart the valves would not close. The contraction of the muscular tissue of the heart gives forth a sound, as does indeed the contraction of other muscles, and this

is also an element in producing the first sound. The striking of the apex against the chest-wall, the so-called apex-beat, formerly regarded as one of the factors of the first sound, can take no part in its production, because, as has been pointed out, this action does not take place.

Every student should familiarize himself with the cardiac sounds, not simply by reading about them, but by listening to the human chest. A thorough knowledge of their character is essential to a comprehension of the diseases of the heart. It is important to remember that the impulse of the heart, the systole of the ventricles, the first sound, and the closure of the mitral and tricuspid valves are synchronous, and that when the second sound is heard the ventricles are beginning their diastole and the aortic and pulmonary valves have just closed.

**Cardiac Innervation.**—The cause of the beat of the heart has not been definitely ascertained. The fact that it beats when removed from the body shows that this action is dependent upon some power within itself. The length of time that a heart so isolated will continue to beat varies in different animals, being longer in the poikilothermal than in the homoiothermal; thus, it may continue for days in the former, while in the latter it may cease after a few hours or even minutes. Landois states that in hearts that have been excised “the last vestige of cardiac action has been observed in the rabbit after  $15\frac{1}{2}$  hours, in the mouse after  $46\frac{1}{2}$  hours, in the dog after  $96\frac{1}{2}$  hours, and in a three-months’-old human embryo after 4 hours.”

Two theories have been advanced to explain the beat of the heart: (1) That it is due to stimuli having their origin in nerve-ganglia which exist in the heart; and (2) that it is due to an inherent power of contraction residing in the cardiac muscle-cells, a power independent of any nervous connection whatsoever, and that this is due to the action upon the heart muscle of chemical substances in the blood, as calcium, sodium, and potassium salts; the first being apparently essential for the chemical stimulation, while a certain proportion of potassium is also necessary (Howell). The effect of the sodium chlorid is to maintain the osmotic equilibrium between the muscle-cells and the surrounding liquid.

The first of these theories is supported by the fact that there are numerous ganglion-cells in the heart, and that where these are most abundant, as in the auricle, there the power of contraction is greater than in the part (the ventricle) where the cells are fewer; and, further, that when the apex of the heart—*i. e.*, the point of the ventricle in which there are no cells—is cut away, it no longer beats. The second theory derives its support from the fact that a piece of the apex of the ventricle of a tortoise, in which there are no ganglion-cells, when suspended in a moist chamber, will beat for hours. The apex of a dog’s heart, in which there are no cells,



will beat for hours, provided it is supplied with defibrinated blood through its nutrient artery (Porter). This second theory is rapidly gaining favor among physiologists.

**Cardiac Nerves.**—Whatever may be the cause of the heart-beat, its regulation is brought about by the central nervous system. The cardiac nerves are derived from two sources, the vagus and the sympathetic, through the cardiac plexuses, of which there are four: 1, the superficial, situated in the concavity of the arch of the aorta; 2, the deep, or great; 3, the right coronary, and, 4, the left coronary; the last two being derived from the superficial and the deep. The impulses which reach the heart through the vagus are of an inhibitory nature, while those passing through the sympathetic are accelerating or augmenting (pp. 487 and 523).

**Circulation in the Arteries.**—Each time that the ventricles contract they send into the arteries about 140 c.c. of blood, each ventricle expelling 70 c.c. (p. 314). The arterial system is always overdilated—that is, even when the heart is at rest the amount of blood in the arteries is sufficient to stretch their walls a little. When an additional amount of blood is forced into them by the muscular contraction of the heart, these vessels are dilated still more, for the blood already in them cannot at once flow on in an amount equal to that which comes from the heart. If an artery at this time should be felt with the finger, it would beat against the latter, this beat being called the *pulse*. As soon as the systole ceases the elastic coats of the arteries squeeze the blood that is within them, and this blood tends to flow away from the point of pressure in two directions—back toward the heart and onward toward the capillaries. Its backward flow at once closes the pulmonary and aortic valves, and in this direction, therefore, its progress is barred. The blood then can go only forward. Before the onward flow of the blood has ceased another systole occurs, and again the ventricles are emptied into the arteries, and thus this action continues during the life of the individual. If a cannula is inserted into the cavity of the ventricle, it will be seen that at each systole the blood spurts out in a jet, which ceases at the end of the systole—that is, the flow from the heart is intermittent. If the cannula is inserted into the aorta, the blood will jet out at each systole of the heart, but, instead of ceasing to flow during diastole, it will not entirely cease, but will continue to flow a little under the influence of the elastic force of the aorta. If the cannula is inserted into successive portions of the arterial system farther and farther from the heart, the blood will come out in jets as before under the influence of the heart's contraction, but it will continue to flow in the intervals, the difference between the jet and the continuous flow being less and less marked the greater is the distance of the insertion of the cannula from the heart. In the capillaries the flow is regular and continuous, unaffected by the action of the heart.

**Internal Friction.**—If the blood is studied as it is flowing through a small artery in the web of a frog's foot, it will be seen that in the center of the current it is flowing much faster than at the sides; this is the *axial stream*, and in it will be observed the red corpuscles. That portion of the current which is between the axial stream and the walls of the vessel moves more slowly, the rate diminishing from the center outward, until at the walls themselves it is at the minimum. This outer portion is known as the *inert layer*. It should be stated that this arrangement of the current is not due to any peculiarity of the blood or of the vessels through which it flows, but is present in every fluid while flowing through a tube. Between the different layers of fluid there is friction, called *internal friction*. The smaller the tubes the greater the internal friction, so that the amount of friction in the subdivisions of the aorta and its numerous ramifications is very great, and this friction acts as an obstacle to the outflow of the blood, constituting *peripheral resistance*.

## BLOOD-PRESSURE.

The systemic circulation of the blood—i. e., its flow from the left ventricle through the arteries and capillaries; and back by the veins to the right ventricle again—is a movement from a point of high pressure, the left ventricle, to one of low pressure, the right

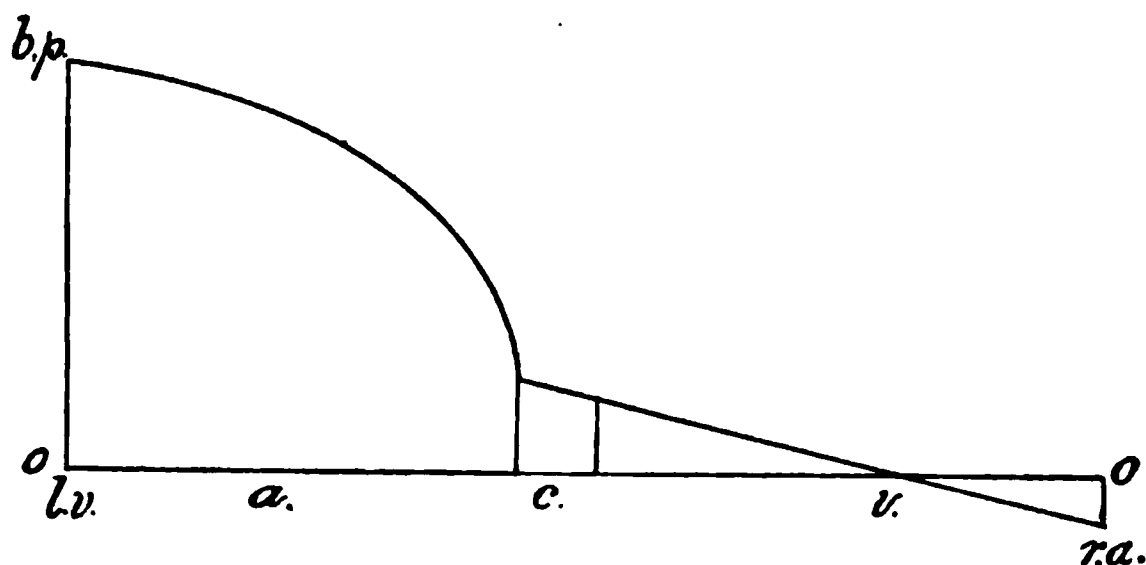


FIG. 165.—Height of blood-pressure (*b.p.*) in left ventricle (*l.v.*): *a.*, arteries; *c.*, capillaries; *v.*, veins; *r.a.*, right auricle; *o o*, line of no pressure (after Starling).

auricle. This is shown in Fig. 165, where the pressure is greatest at the left ventricle, gradually diminishing in the large arteries, until at the end of the arterial system the fall is abrupt; it falls gradually throughout the capillaries and veins until the large veins in proximity to the heart are reached, where it is negative (p. 323).

The fact that the blood within the vessels is under varying degrees of pressure may be demonstrated by repeating the classic experiment performed by Stephen Hales, an English Episcopal clergyman, and described by him in "Statical Essays, Containing Hæmostaticks." This was published in London in 1733. He in-



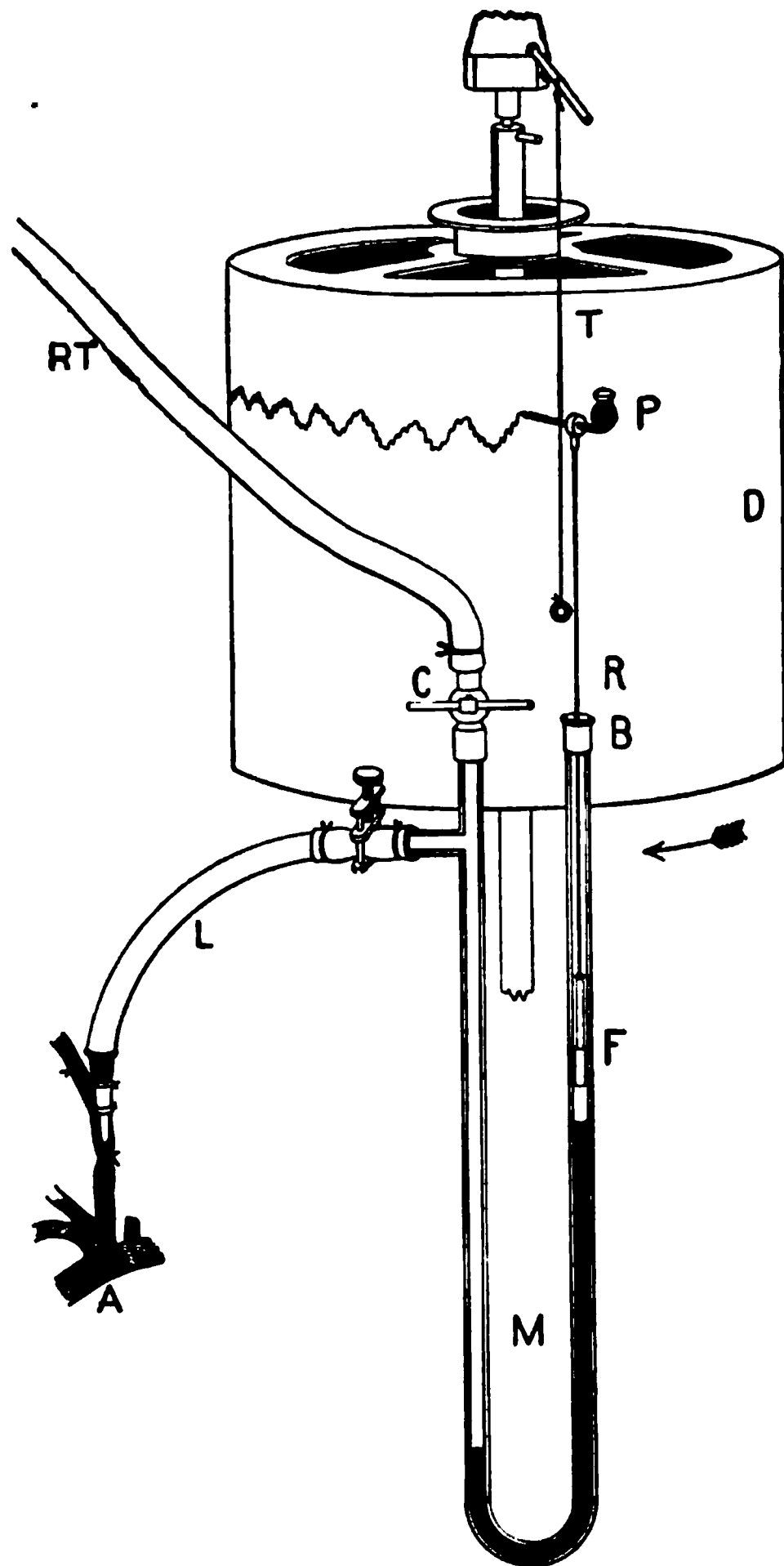


FIG. 166.—Diagram of the recording mercurial manometer and the kymograph; the mercury is indicated in deep black: *M*, the manometer, connected by the leaden pipe *L* with a glass cannula tied into the proximal stump of the left common carotid artery of a dog; *A*, the aorta; *C*, the stop-cock, by opening which the manometer may be made to communicate through *RT*, the rubber tube, with a pressure-bottle of solution of sodium carbonate; *F*, the float of ivory and hard rubber; *R*, the light steel rod, kept perpendicular by *B*, the steel bearing; *P*, the glass capillary pen charged with quickly drying ink; *T*, a thread which is caused, by the weight of a light ring of metal suspended from it, to press the pen obliquely and gently against the paper with which is covered *D*, the brass "drum" of the kymograph, which drum revolves in the direction of the arrow. The supports of the manometer and the body and clock-work of the kymograph are omitted for the sake of simplicity. The aorta and its branches are drawn disproportionately large for the sake of clearness (Curtis).

roduced into the femoral artery of a horse a brass-pipe whose bore was one-sixth of an inch in diameter, to that, by means of

another brass-pipe which was fitly adapted to it, "was attached a glass tube of nearly the same diameter, which was nine feet in length"; the blood rose to a height of 2.44 meters, and at each inspiration of the animal the column rose and at each expiration it fell; besides this movement due to respiration, there was a smaller rise at each systole and a corresponding fall at each diastole. This pressure under which the blood is in the artery which causes it to rise so high in the tube is *arterial pressure*, or the blood-pressure in the arteries. Such an instrument for measuring pressure is a **manometer**. It is manifest that a glass tube 2½ meters in height is not a very convenient instrument to manipulate, and besides the blood soon clots. To obviate both of these difficulties the *mercurial manometer* was devised, together with the use of a solution of sodium carbonate; the latter preventing the coagulation of the blood. Later a drum or *kymograph* was added to the apparatus, on which a record could be made for study and preservation (Fig. 166). The legend beneath the illustration is sufficiently descriptive of the complete apparatus. The curve

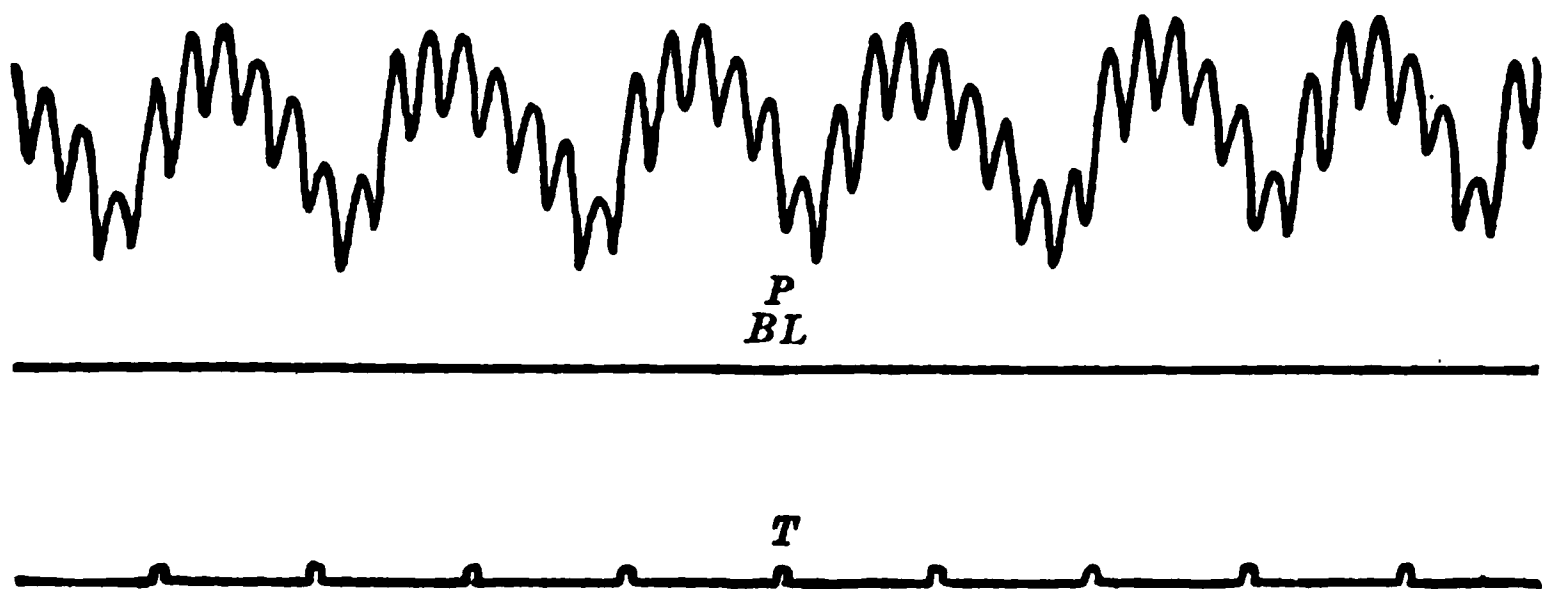


FIG. 167.—The trace of arterial blood-pressure from a dog anesthetized with morphia and ether. The cannula was in the proximal stump of the common carotid artery. The curve is to be read from left to right: *P*, the pressure-trace written by the recording mercurial manometer; *B L*, the base-line or abscissa, representing the pressure of the atmosphere. The distance between the base-line and the pressure-curve varies, in the original trace, between 62 and 77 millimeters, therefore the pressure varies between 124 and 154 millimeters of mercury, less a small correction for the weight of the sodium-carbonate solution; *T*, the time-trace, made up of intervals of two seconds each, and written by an electro-magnetic chronograph (Curtis).

made by the pen is shown in Fig. 167. The longer waves are due to respiration, the smaller ones to the heart-beat. By the term *mean pressure* is meant the average pressure throughout the observation. The mean arterial pressure in man is approximately 150 mm., an increase of 5 mm. occurring at the time of systole.

The figures here given for the mean aortic pressure may be too high; it has, of course, never been measured in man. The following table (Starling) gives the approximate heights in different portions of the vascular system, calculated largely from observations in lower animals:

Large arteries ( <i>e. g.</i> , carotid) . . . . .	+ 140	mm. of mercury.
Medium arteries ( <i>e. g.</i> , radial) . . . . .	+ 110	" "
Capillaries . . . . .	+ 15 to + 20	" "
Small veins of arm . . . . .	+ 9	" "
Portal vein . . . . .	+ 10	" "
Inferior vena cava . . . . .	+ 3	" "
Large veins of neck . . . . .	from 0 to - 8	" "

**The Sphygmometer** (Fig. 168).—The sphygmometer is an instrument for ascertaining the blood-pressure in the human subject. It consists of a rubber bag, containing a colored fluid, connected with a graduated glass tube, the top of which is expanded into a bulb and closed with a stopcock. The instrument is so attached to the body that the rubber bag is on the artery whose blood-pressure is to be ascertained. The bag being pressed down upon the artery, the fluid rises in the tube, and the air in the bulb, being compressed, acts as an elastic spring. The top of the fluid is watched carefully, and when its pulsation is greatest, which is known as the *maximal pulsation*, its height is read off on the scale; this is so graduated as to correspond to millimeters of mercury pressure, and represents the arterial pressure. By this instrument the radial pressure of an adult has

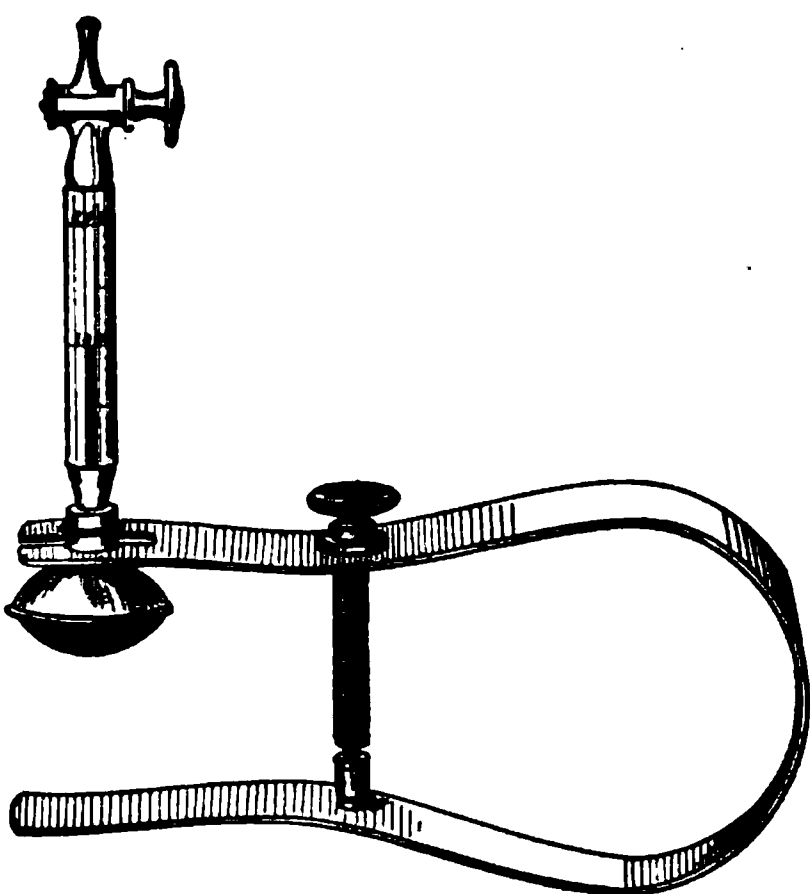


FIG. 168.—Hill and Barnard's sphygmometer.

been found to be from 110 to 120 mm. of mercury. The instrument can also be used to obtain venous pressure.

Stewart states that the blood-pressure in the radial artery of a healthy man may average 150 mm. of mercury. In the anterior tibial artery of a boy whose leg was to be amputated, it was found to vary from 100 mm. to 160 mm. according to the position of the body and other circumstances. The pressure in the pulmonary artery is about one-third that in the aorta. The mean press-

ure in the veins is perhaps 5 mm. and in the great veins near the heart negative, so that a cannula introduced into this part of the circulatory system would show a depression of the mercury in the distal limb of the manometer, indicating that there was a suction from within the vein; this constitutes *negative pressure*. It is the pressure under which the blood is in the arteries that causes it to spurt or jet when the vessel is cut, while the flow from a wounded vein or capillary is continuous.

*Fick's spring myograph* is another form of this instrument, in which the movements of a hollow spring are communicated to a writing lever.

### RATE OF BLOOD-FLOW IN THE VESSELS.

The caliber of the blood-vessels is constantly changing, and the rate of the flow of blood through them is subject to great variations, so that any estimate of the velocity of the flow can at best be but approximate. There are two factors which enter into the problem: (1) the caliber of the vessel at the point where the velocity is to be ascertained, and (2) the amount of blood passing that point in a given time, for the velocity is inversely proportional to the sectional area.

**Rate of Flow in the Arteries.**—It is in these vessels that the velocity is the greatest, beginning at the heart and gradually diminishing along the course of the arterial system. Its maximum is at the time of the systole.

**The Stromuhr.**—One of the instruments used to determine the rate of speed is the *stromuhr* of Ludwig (Fig. 169). This consists of a U-shaped tube, glass above and metal below, expanded into two bulbs, A and B, which can be filled from the top. The lower extremities of these tubes are connected with the ends of a divided artery, so that the channel between the two is continuous through the stromuhr. The instrument is so constructed that while in place the upper portion, including the bulbs, can be so rotated at *c* as to bring A in connection with *b*, and B with *a*, and this process repeated as often as desired, the flow through the instrument not being interrupted. The tubes and the bulb B are filled with defibrinated blood, which in A

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FIG. 169.—Diagram of longitudinal section of Ludwig's "stromuhr." The arrows mark the direction of the blood-stream. For further description see the text (Curtis).

reaches only up to the mark *e*; and the bulb A is filled with oil. The clamps which close the ends of the vessel are now removed, the time being noted, and the blood from *a* expels the oil in A into B. When A is filled with blood to the point *d*, the time is again noted, and the capacity of A, and the caliber of the vessel being known, the velocity of the flow may be calculated. A single measurement would not be sufficient to give results of much value; but if at the moment the blood reaches *d* the instrument is rotated, the bulb B into which the oil has been driven by the blood will be brought into relation with *a*, and will be filled with blood from the vessel, as A originally was, the oil being forced into A, and the blood contained in that bulb will be driven on into the vessel *b*, thus entering the circulation again. When the oil emerging from the bulb reaches the mark, the time is again noted, and the bulb again rotated; thus the blood which is measured is always the volume between *e* and *d* in A. The time between the rotations is the time occupied in filling the bulb, and this may be recorded on a kymograph.

**The Dromograph (Fig. 170).—**

This consists of a metal tube, which is inserted into a divided artery; in the side of the tube is an opening, closed by rubber, through which a lever passes, one end being inside the vessel, the other outside, and so arranged that its movements are indicated on a dial. The number of graduations corresponding to a given velocity is known by observing the deflection of the lever when it is inserted into a rubber tube through which water flowing at a known rate is passing.

**FIG. 170.—Chauveau's dromograph:** A, tube connected with blood-vessel; B, metal cylinder in communication with A. The upper end of B has a hole in the center, which is covered by a membrane, *m*, through which a lever, C, passes; C has a small disk, *p*, at its lower end, which projects into the lumen of A, and is deflected in the direction of the blood-stream through A. The deflection is registered by a recording tambour in communication by the tube E with a tambour D, the flexible membrane of which is connected with the lever of the pendulum C.

Various observations have been made on lower animals to

determine the velocity of the blood-flow in the arteries. In the dog's carotid it is found to be from 205 mm. to 350 mm. per second; in the same vessel of a horse, 306 mm.; and in the metatarsal artery of the horse, 56 mm. When an artery divides, the sectional area of the branches is more than that of the original vessel, and this consequently results in a gradually increasing sectional area, and a corresponding diminution in the velocity of the flow, so that in the smaller artery the speed is

greatly reduced. The velocity in the large arteries may be considered as approximately 3 dm. a second.

**Rate of Flow in the Capillaries.**—The sectional area of the capillaries is 700 times greater than that of the aorta, where the velocity is, perhaps, 500 mm. per second; when this portion of the circulatory apparatus is reached the rate of flow is greatly reduced, being in the dog from 0.5 mm. to 0.75 mm. per second.

The rate of flow through the capillaries of the retina has been ascertained by Vierordt in his own eye to be from 0.6 mm. to 0.9 mm. per second.

The length of any given capillary through which a specified portion of the blood passes is only 0.5 mm., so that the length of time such portion would remain in the capillary system would be less than a second, and yet during this brief time important interchanges take place between the blood and the tissues. It is here that the tissues receive from the blood the materials they require for their nutrition, and in the case of glands for their secretion; and it is likewise here that the blood receives from the tissues their waste products. The thin walls of the capillaries are admirably adapted for this interchange. In fact, it is within bounds to say that the heart, the arteries, and the veins are simply subsidiary to the capillaries, the arteries carrying to these vessels the blood which the heart pumps into them, while the veins return the blood to the heart.

**Rate of Flow in the Veins.**—It is estimated that the sectional area of the veins is at least twice as great as that of the arteries, and therefore the velocity would be twice as great in the arteries as in the veins. Some estimate the area of the veins as three times that of the arteries. Inasmuch as the sectional area of the veins decreases as the heart is approached, the rate of flow in these vessels gradually increases.

**The Circulation-time.**—The length of time which the blood takes to make the entire round of the body was first ascertained by dividing the jugular vein and injecting a solution of potassium ferrocyanid into the end nearest the heart; the blood was collected from the vein of the other side and tested by adding a solution of ferric chlorid to the serum; as soon as the Prussian-blue reaction appeared it was demonstrated that the blood had completed the circulation of the body. These observations conducted on different animals gave the following results: In the horse, 31.5 seconds; dog, 16.7 seconds; cat, 6.69 seconds; and goose, 10.89 seconds.

It was also found that this represented the time occupied by 27 heart-beats in each animal. If 72 times a minute are considered as representing the average number of beats in man, it will be seen that the blood requires 22.5 seconds to complete the entire circulation.

Stewart has devised a method for ascertaining the circulation-

time by injecting into the vessels methylene-blue, the color of which shows through the blood-vessels. By this means he has been able to study the circulation-time in the lungs, kidney, stomach, and other organs of lower animals. He thinks that the pulmonary circulation-time—*i. e.*, the time occupied by the blood in passing through the pulmonary circulation—is not usually much less than 12 seconds nor more than 15 seconds; the circulation-time of the kidney, spleen, and liver is relatively long and much more variable than that of the lungs, these organs being easily affected by exposure and changes of temperature (increased by cold, diminished by warmth), and that of the retina and heart is the shortest of all. The total circulation-time in man he thinks is not much less than a minute, nor more than a minute and a quarter.

### THE PULSE.

As has been seen, the left ventricle expels at each beat about 70 c.c. of blood, pumping it into the elastic arteries; these being already filled, are still further distended by this additional amount, and the elastic coat of the artery recoils upon the blood within the vessel, driving it still further along. If a finger is placed upon an artery, this distention can be recognized, and constitutes the *pulse*. When the ventricle ceases its systole and begins its diastole, although blood ceases to be expelled from it, still the current in the arteries does not cease, for the elastic force of the vessels is sufficient to keep up a continuous movement of the fluid, which while it is in the arterial system is affected by the pulsation of the heart, but which in the capillary and venous systems, is uniform in rate. If it was possible to place a finger upon the carotid, another on the radial, and still another on the dorsal artery of the foot, it would be found that the pulse would first be felt in the artery nearest the heart, then in that at the wrist, and finally in the most distant one. Thus the pulse-wave starting at the left ventricle is felt in 0.159 second at the wrist, and in 0.193 second at the foot. It travels at the rate of about 9 meters per second.

The number of pulsations varies in different conditions, increasing in activity and diminishing during rest; it also varies at different ages: At birth it is 140 to the minute; at one year, 120; two years, 110; three years, 90; seven years, 85; puberty, 80; adult age, 70; old age, 60. These figures are approximate only.

Any artery which is accessible may be used to obtain the pulse, but physicians have selected the radial as the most convenient because of its accessibility and also because it lies upon an unyielding bony bed, and can be readily compressed by the finger and its character studied. The heart is one of the vital organs of the body, and a knowledge as to how it is performing its functions is very important for the physician to possess. Situated as it is within the thorax, he cannot examine it directly, and is therefore



compelled to resort to other means to ascertain its condition. One of the best sources of information is the pulse. This he studies to learn: (1) The *frequency* of the heart-beats, for each time the

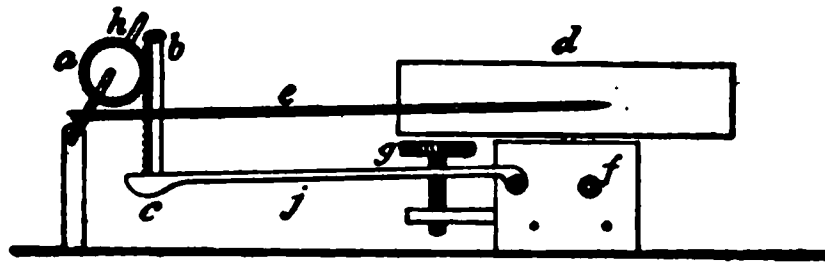


FIG. 171.—Scheme of Marey's sphygmograph: *a*, toothed wheel connected with axle *h*, and gearing into toothed upright *b*; *c*, ivory pad which rests over blood-vessel and is pressed on it by moving *g*, a screw passing through the spring *j*; *e*, writing-lever attached to axle *h*, and moved by its rotation; *e* writes on *d*, a traveling surface moved by clockwork *f*.

ventricle contracts there is a corresponding beat of the pulse; (2) the *force* with which the heart is acting, for the strength of the pulse is an indication of that of the heart; (3) its *regularity*; and



FIG. 172.—Sphygmogram from a normal human radial pulse beating from 58 to 60 times a minute. To be read from left to right (Burdon-Sanderson).

(4) its *tension*—*i. e.*, whether it is compressible or not, whether a slight pressure will obliterate it, or whether it requires a greater amount of pressure. Low tension implies low arterial pressure, and high pressure denotes high blood-pressure.

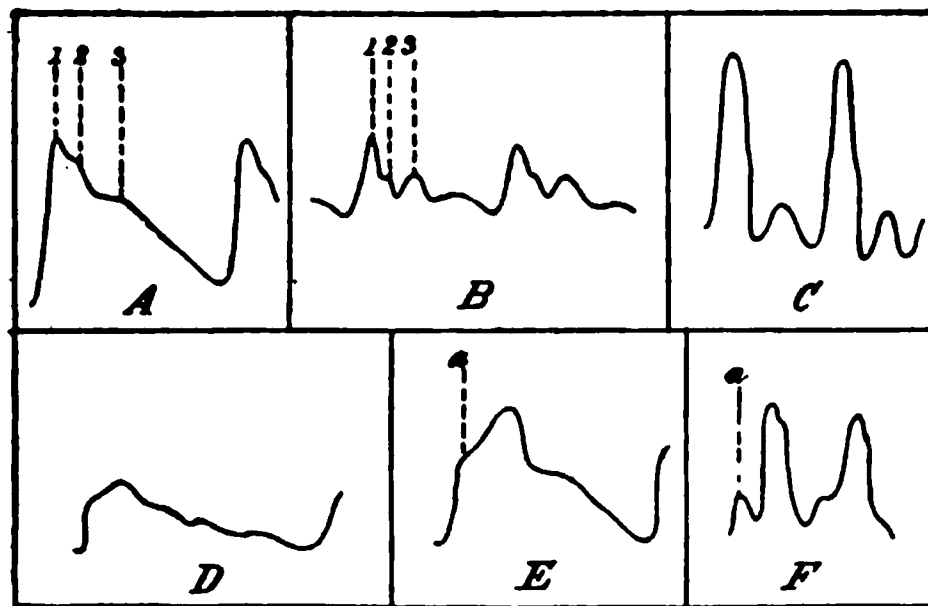


FIG. 173.—Pulse-tracings: 1, primary elevation; 2, predicrotic or first tidal wave; 3, dicrotic wave. The depression between 2 and 3 is the dicrotic or aortic notch; 3 is better marked in *B* than in *A*. *C*, dicrotic pulse with low arterial pressure. *D*, pulse with high arterial pressure—summit of primary elevation in the form of an ascending plateau. *E*, systolic anacrotic pulse; the secondary wavelet *a* occurs during the upstroke corresponding to the ventricular systole. *F*, presystolic anacrotic pulse; *a* occurs just before the systole of the ventricle. In this rarer form of anacrotism *a* may sometimes be due to the auricular systole when the aortic valves are incompetent (Stewart).

**The Sphygmograph** (Fig. 171).—This instrument makes a record, *sphygmogram* or *pulse-trace*, of the pressure in the



arteries. It is attached to the wrist, and the point of the lever makes a sphygmogram upon the card previously smoked. It is an instrument which needs great care in its use in order to make its records of practical value. Fig. 172 shows a sphygmogram of the radial pulse. It represents five complete pulsations of the artery and the beginning of a sixth. The upstroke is caused by the expansion of the artery due to the arrival of the pulse-wave, while the downstroke is due to the retraction of the vessel. The upstroke, the *primary* or *percussion-wave*, is abrupt, because the systole of the left ventricle is abrupt, but the down-

FIG. 174.—Plethysmograph for arm: F, float attached by A to a lever which records variations of level of the water in B, and therefore variations in the volume of the arm in the glass vessel C. Or the plethysmograph may be connected to a recording tambour. The tubulure at the upper part of C is closed when the tracing is being taken (Stewart).

stroke is gradual, because of the fact that the return of the artery to its former condition is gradual by virtue of its elasticity. The downstroke is seen to be made up of a number of waves: First, the *predicrotic* or *tidal* wave; second, the *dicrotic* wave; and third, the *post-dicrotic* wave. These sec-

FIG. 175.—Plethysmograph tracing from arm. The tracing was taken by means of a tambour connected with the plethysmograph; the dicrotic wave is distinctly marked (Stewart).

ondary waves of the downstroke are termed *katacrotic*. There is sometimes a secondary wave in the upstroke, called *anacrotic*. The predicrotic and post-dicrotic waves are supposed to be due

to the elastic tension of the arteries, and are therefore more marked when this is at its highest. They are also caused to some extent by oscillation of the sphygmograph. Their causes are not thoroughly understood.

The dicrotic wave is, on the other hand, a very constant and valuable feature of the sphygmogram. It is probably caused by a second wave, which is produced by the closure of the aortic valve, although on this point opinions are at variance. The arteries are already filled when the left ventricle throws in its contents, causing the expansion of the aorta and putting its elastic coat upon the stretch; when the systole is at an end the elastic recoil upon the blood drives this fluid both forward and backward; the backward flow closes the aortic valve, and, being suddenly brought to a standstill, a wave of blood is produced which is propagated along the arterial system closely following the primary wave and causing the dicrotic wave. This is sometimes so marked that it can be felt by the finger, constituting the *dicrotic pulse*; thus each pulsation of the heart produces 2 pulse-beats. The sphygmograph shows this condition much better than the finger.

**The Plethysmograph** (Fig. 174).—This is an instrument for recording the *volume-pulse*—*i. e.*, the increase in the volume of an artery caused by the pulse-wave. It consists of a chamber into which the organ to be experimented upon is inserted and filled with fluid, the opening being closed with a rubber band. At the other end is a rubber tube communicating with a vessel, in which is also fluid, and on its surface a float with a writing-point attached, which is so arranged as to record on a drum. If the arm is placed in the chamber in the manner illustrated, at every contraction of the ventricle the volume of blood in the arteries will be increased, and a movement be set up in the fluid which will cause the float to rise; when the diastole occurs the float will sink. The record made is called a *plethysmogram* (Fig. 175).

### CIRCULATION IN THE VEINS.

The forces which propel the blood through the arteries and capillaries—*i. e.*, the contractile force of the ventricles and the elastic force of the arteries, collectively called the *vis a tergo*—are sufficient to carry the blood back to the heart through the veins; for, as has been stated, the pressure in the aorta is equal to a column of mercury 200 mm. in height, while in the veins it is at most only 5 mm., and sometimes actually negative, so that there is a difference in pressure of 195 mm. of mercury. This *vis a tergo* is, however, aided by two other forces: (1) compression of the veins and (2) aspiration of the thorax.

**Compression of the Veins.**—It will be remembered that in the veins there are, at different points along their course, valves

which are so arranged as to permit the blood to flow in but one direction—that is, toward the heart. Many of these veins are so situated with reference to muscles that when the muscles contract the contiguous veins are compressed. This compression forces the contained blood away from the points of pressure, and as the closure of the valves prevents the blood from flowing backward, it must go forward.

**Aspiration of the Thorax.**—At each inspiration the cavity of the chest is enlarged and the pressure on its contents is diminished. One of the results of this inspiration is the inflowing of air. Another result is the inflowing of blood into the venæ cavæ and right auricle, for while the intrathoracic pressure is diminished, that upon the blood-vessels outside remains the same. A similar tendency exists for the blood in the aorta to flow back into the left ventricle, but this is prevented by the aortic valve. This subject will be again discussed in connection with respiration.

**Force of Gravity.**—The force of gravity assists in the return of the blood to the heart from the upper portions of the body, but retards its return from the lower portions, so that as a factor in aiding the circulation as a whole it may be ignored. This force may, however, be utilized whenever for any reason there is congestion in a part—as, for instance, in a foot the seat of inflammation. In such a case the elevation of the lower extremity facilitates the flow of blood in the veins and proves beneficial. Also, when by reason of an imperfect performance of its function the heart fails to send enough blood to the brain, and fainting occurs, relief will come more promptly if the patient is at once placed on the back, with the head lower than the heart, thus assisting that organ in sending blood to the anemic brain.

## LYMPHATIC SYSTEM.

The lymphatic system is composed of *lymphatic vessels*, *lymphatic glands*, and the *cavities of the serous membranes*.

**Lymphatic Vessels.**—The larger lymphatic vessels structurally are like the veins, being composed of three coats, the middle coat containing both muscular and elastic fibers. Unlike the veins, however, muscular fibers are found in the external coat. The smaller vessels have only a connective-tissue coat lined with endothelium. In the lymphatic vessels, as in the veins, are valves opening toward the heart, but they are nearer together than are those of the venous system. The origin of these vessels in the tissues, as a rule, is by *plexuses* or by *stomata*, as in serous membranes; by blind extremities, as in the lacteals; or by *lacunar interstices*, as in some viscera and glands. They ultimately discharge into the venous system—on the right side through the right lymphatic duct, and on the left side through the thoracic duct.

**Right Lymphatic Duct.**—The lymphatic vessels of the right side of the head, neck, and thorax, and of the right arm, right lung, right side of the heart, and a portion of the convex surface of the liver, discharge into the *right lymphatic duct*, which in turn discharges into the right subclavian vein, at its junction with the right internal jugular vein. It is about 1.25 cm. in length and about 2 mm. in diameter. At its junction with the venous system there are two semilunar valves, to prevent regurgitation of the blood.

**Thoracic Duct.**—All the lymphatics not connected with the right lymphatic duct discharge into the *thoracic duct*. This vessel

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FIG. 176.—Topography of the thoracic duct (Zuckerkindl).

begins at the *receptaculum chyli* or *reservoir* or *cistern of Pecquet*, which is situated upon the body of the second lumbar vertebra, and terminates in the left subclavian vein, where it joins the left internal jugular vein. The duct is from 38 cm. to 45 cm. long, about the size of a goose-quill at commencement and termination, and somewhat smaller in the middle of its course.

**Structure of the Thoracic Duct** (Figs. 176, 177).—The thoracic duct is composed of three coats: an *internal*, composed of a single

layer of endothelium, a subendothelial layer, and an elastic fibrous layer; a *middle*, consisting of connective, elastic, and muscular tissues; and an *external*, also containing connective, elastic, and muscular tissues.

**Lymphatic Glands** (Fig. 178).—The lymphatic glands are bodies of a pale reddish color, and are oval in shape. Their diameter is from 2 mm. to 20 mm. Lymphatic vessels run into the glands—the *afferent*; and out of them—the *efferent*; and through them pass the lymph and the chyle. They consist of a *capsule* of connective tissue, from which are given off *trabeculae*

Longus colli muscle.

Internal jugular vein.

FIG. 177.—Topography of the thoracic duct (Zuckerkindl).

made up of connective tissue with some muscular fiber-cells; these pass into the gland toward the center or *medullary* portion (*M*) for about one-fourth of the distance, dividing this outer or *cortical* portion into *alveoli* (*C*). The trabeculae then divide and subdivide, forming a network in the medullary portion, the spaces between these smaller trabeculae being also alveoli. The alveoli contain *gland-pulp* or *lymphoid tissue*, which consists of retiform tissue with lymph-corpuscles, with numerous capillary blood-vessels. Between the gland-pulp and the trabeculae in the cortical portion there is a space (*l.s*), which is termed a *lymph-path* or *lymph-*

*sinus*. The *afferent* vessel *a.l.* loses all its coats, save the endothelial, as it enters the gland, and this is continuous with that lining the lymph-sinus; the same is true of the *efferent* vessel, which emerges at the *hilum*. The structure of the lymphatic gland is such that the lymph in its flow passes through the pulp and takes up lymphocytes. It may also deposit any poisonous matter which it has absorbed, and thus prevent its entrance into the blood. The arteries supplying blood to the gland enter at the hilum, and the veins emerge at the same point.

—

FIG. 178.—Diagram of a lymphatic gland, showing afferent (*a.l.*) and efferent (*e.l.*) lymphatic vessels; cortical substance (*C*); medullary substance (*M*); fibrous coat (*c*), sending trabeculae (*tr*) into the substance of the gland, where they branch, and in the medullary part form a reticulum; the trabeculae are surrounded by the lymph-path or sinus (*l.s*), which separates them from the adenoid tissue (*l.h*) (Sharpey).

**Cavities of Serous Membranes.**—The serous membranes are closed lymph-sacs, made up of connective tissue lined internally with pavement-epithelial cells, termed endothelium. Between some of these cells are openings—*stomata*—which are surrounded by small protoplasmic cells. They are very distinct in the peritoneal covering of the rabbit's diaphragm. The stomata are openings into the lymphatic vessels through which lymph is pumped by the contraction and dilatation of the serous cavities, brought about by respiration and circulation.

The serous membranes are: (1) *peritoneum*; (2) *pleura*; (3)

*pericardium*, which on account of its fibrous layer is termed *fibro-serous*; (4) *tunica vaginalis testis*.

### CIRCULATING LYMPH.

The lymph and its source having been discussed (p. 302), need not again be referred to. It is taken up by the lymphatic capillaries in the tissues by endosmosis, and, as it accumulates there, gradually fills the larger vessels, and, as it is readily discharged into the venous system, there is set up a current which constitutes the lymphatic circulation. It is to be noted, however, that there is no true circulation, as in the case of the blood. The blood goes out from the heart and returns again, completing a circuit, but here the flow is always in one direction, toward the heart.

Additional aids to the endosmotic force in producing the movement of the lymph are the contractions of the muscles of the body, by which, as in the veins, the lymphatics are compressed, and the lymph, being prevented by the valves from flowing back, is propelled toward the heart. The pressure exerted by the walls of the aorta in its pulsations compresses the thoracic duct in a similar manner, and, as this possesses valves, the onflow of the lymph and chyle is favored. The force of aspiration of the thorax is



FIG. 179.—Endothelial cells from small artery of the mesentery of a rabbit: stained with silver nitrate and hematoxylin (Huber).

also a factor in the movement of the lymph, acting as was stated in the case of the venous blood. It has been estimated that the amount of lymph absorbed daily in a human adult is about 2000 grams, and of lymph and chyle together 3000 grams.

### DUCTLESS GLANDS.

This term includes the spleen, the thyroid and parathyroids, the thymus, the suprarenal capsules, the pineal gland, the pituitary body, the carotid and coccygeal glands, and the lymphatic glands, the last of which we have already considered. They have received this name because they lack secretory ducts. For the reason that they are believed by some to have important relations to the blood they are sometimes described as *blood-glands* or *vascular glands*.

We have seen that although the lymphatic glands have no

proper duct, still there are added to the lymph during its passage through the glands the lymphocytes, which are a product of the gland, and it is now held that in a similar manner while the blood is passing through the ductless glands their product is added to it. This product is regarded as an *internal secretion*.

### THE SPLEEN.

The spleen is the largest of the ductless glands, and its function is, doubtless, the most important. Its location is in the left

sl.

p.

Trabecula

cor-  
with  
nter.

FIG. 180.—Part of a section through the human spleen :  $\times 75$  (sublimite fixation).  
At *a* is an oblong Malpighian body with a blood-vessel (Böhm and Davidoff).

hypochondrium between the stomach and diaphragm. Instances are on record in which the organ was absent, while sometimes it is so divided as to present the appearance of a considerable number of small spleens.

**Weight.**—The weight of the spleen varies at different periods of life, being at birth to the entire body as 1 is to 350 ; in adult life, as 1 to 320 and 400 ; and in old age, as 1 to 700, while in



certain diseased conditions, such as ague, syphilis, or heart disease, it may be enormously increased, in some cases as much as 1 to 7, or 9 kilograms, the average normal weight being about 176 grams in the cadaver, or about 225 grams during life, on account of the contained blood. Its color is dark red. The size of the spleen is greatest during digestion, and least during starvation.

**Chemical Composition.**—The spleen consists of about 75 per cent. water and 25 per cent. solids, of which only about 1 per cent. is inorganic, a part being iron. The organic ingredients are proteids, among them being a cell-globulin and a nucleoproteid; whether peptones exist or not is still undecided; hemoglobin, xanthin, uric acid, glycogen, cholesterin, lecithin, and the fatty acids, formic, acetic, and butyric. The reaction of the gland

venous  
vein.  
thoma.  
cord.  
vein.  
vein.

FIG. 181.—Diagram of lobule of the spleen (Mall, *Johns Hopkins Hospital Bulletin*, Sept., Oct., 1898).

is alkaline during life, becoming acid after death, due to the formation of sarcolactic acid.

**Structure.**—The outer covering is peritoneal, and is closely adherent to the fibro-elastic coat or *tunica propria*, the two forming practically one. From it are given off *trabeculae*, which form the framework of the organ, in the interspaces of which, *areolae*, is the *splenic pulp*, a soft material with a reddish-brown color, within which are whitish bodies, *Malpighian corpuscles* (Figs. 180, 181), composed of lymphoid tissue, and having a diameter of from  $\frac{1}{4}$  mm. to 1 mm. The spleen-pulp, when examined under the microscope, is seen to be made up of connective-tissue corpuscles, the *sustentacular* cells, from which are given off processes that form by their union a network in the areolae of which is blood, characterized by a large number of white corpuscles. The

sustentacular cells possess ameboid movement, and in some of them reddish granules, resembling hematin, are seen; also red corpuscles in various stages of disintegration. In young spleens Klein has seen these cells each with a large nucleus from which project bud-like processes, and it has been suggested that these are possibly white corpuscles in the process of formation.

The **splenic artery** enters the spleen at the *hilum*, after having divided into a number of branches (Fig. 181) and being covered by sheaths from the fibro-elastic coat. These arteries divide and subdivide and finally end in the pulp in small arterioles, their external coat gradually changing from connective tissue to lymphoid tissue in which enlargements occur the *Malpighian corpuscles*. These consist of a delicate reticulum enclosing lymph-corpuscles. The cells which make up the reticulum possess ameboid movement.

The arterioles end in capillaries, which later cease to be distinct vessels, the cells making up their walls becoming branched and the branches uniting with the processes of the sustentacular cells. The blood which reaches the pulp through these vessels is by this means brought into direct relation with it. It is again collected into vessels which ultimately become veins that emerge from the hilum as the splenic vein.

**Innervation of the Spleen**—The nerves which are distributed to the spleen are derived from the celiac plexus and right vagus.

**Functions.**—The spleen has been frequently removed from lower animals and from man. In the human being this operation, splenectomy, is performed for wounds of the organ, "wandering spleen" and enlargement due to malaria, and that accompanied with anemia. Splenectomy, for enlargement associated with leukemia, is accompanied with so much hemorrhage that it is, by excellent authority, regarded as unjustifiable.

In the chapter on "Surgery of the Lymphatic System," by Prof. Warren in the *International Text-Book of Surgery*, the author says that the results of the many operations already reported show that the spleen is not an organ in any way essential to healthy existence. A diminution in hemoglobin and in the number of red corpuscles is a constant sequel to splenectomy in animals as in man. This diminution reaches its height two to three weeks after the operation, and then gradually disappears. There is also a temporary leukocytosis, including the polynuclear form, the lymphocytes, and the eosinophiles. In some instances the lymph-glands and the thyroid are enlarged, and an increased vascularity of the bone-marrow occurs in animals.

One of the most striking phenomena presented by the spleen is the change in size which occurs during digestion. This begins after a meal has been taken, and continues for about five hours, when the maximum is reached, after which its decrease begins. This has

been supposed to indicate that the spleen serves as a reservoir for the blood which is needed during the time of digestion, and especially for that taking place in the stomach. The enlargement is caused by relaxation of its muscular tissue and a dilatation of the blood-vessels.

A peculiar movement of contraction and expansion has been found by Roy to occur in this organ at intervals of about a minute. This he demonstrated by the use of an *oncometer* (Fig. 182). The principle on which this is constructed is the same as that of the plethysmograph (p. 329). It is a metal box made up of two halves, fitted together in such manner that they can be tightly closed, openings being left for the vessels of the organ which is enclosed, be it spleen or kidney. To each half is attached a membrane between which and the metal is a space filled with oil. Any increase in the size of the contained organ is accompanied by an expulsion of the oil, which returns when the organ becomes smaller. These changes are recorded by the oncograph.

While the functions of the spleen have not as yet been satisfactorily determined, still they are doubtless comprehended in the various theories which have from time to time been formulated.

A

B

FIG. 182.—Roy's oncometer for spleen: A, open; B, closed.

(1) It is a *producer of white blood-corpuscles*. As to this function there is great unanimity of opinion. The blood emerging by the splenic vein contains more of these cells than that which enters the gland, and this number is greatly increased in *leukocythemia* or *leukemia*, in which the spleen and the Malpighian corpuscles especially are hypertrophied. This disease may also be due to affections of other organs, as the bone-marrow and lymphatics.

(2) It *destroys red blood-corpuscles*. This theory is based upon the fact that red blood-cells are found in the pulp in different

degrees of disintegration, and this is supposed to be brought about by the ameboid cells hitherto described (p. 336). It is stated that in the cells of the spleen hemoglobin is found in different degrees of transformation into other pigments, and a considerable amount of iron is also found in the splenic tissue. It is rather remarkable that if hemoglobin is set free or changed into bile-pigment, one or the other of these substances is not found in the blood of the splenic vein, and yet this is the fact.

(3) It is a *producer of red blood-corpuscles*. The formation of red blood-corpuscles does, doubtless, take place during fetal life and for a short time after birth in man, but there is no evidence that this function exists in the human adult, though it does in some animals, as the rabbit. Laudenbach found that in this animal after an extensive hemorrhage nucleated *erythroblasts* or *hematoblasts* are found in the splenic pulp and in the blood of the splenic vein, and that if the spleen is removed the number of red corpuscles is diminished, as is also the hemoglobin. In an animal whose spleen has been removed the return of the red corpuscles to their normal number is much delayed.

(4) It is a *producer of uric acid*. From the fact that uric acid, as also xanthin, has been found in the spleen, it has been inferred that this is one of its functions. The same is true of lymphoid tissue generally, so that this function cannot be considered as one of the characteristic functions of the spleen.

(5) It is an *enzyme producer*. Some experimenters have found that an enzyme is produced by the spleen which when carried by the blood to the pancreas converts the trypsinogen into trypsin. This theory lacks confirmation.

Schäfer sums up his views on the functions of this organ in the following language: "Whatever may be the nature of its functions in relation to the blood, it is certain that the organ is in no way essential to the normal nutrition of the body. It is, on the other hand, not at all improbable that the main function of the spleen is to serve a mechanical purpose, answering as a reservoir at certain periods of digestion for the blood which has to pass through the portal system; and the fact that, as was first shown by Roy, the spleen normally exhibits regular rhythmic contractions and dilatations, seems to point to its exercising an influence in assisting the flow of blood through the portal vein, and thus through the liver."

## THE THYROID AND PARATHYROID.

The *thyroid gland* is also called the *thyroid body*; it is situated in front of the trachea or windpipe, and consists of the *lobes* united by an *isthmus*. It weighs from 30 to 60 grams, and is larger in females than males, and is said to be larger during menstruation.

**Chemical Composition.**—An analysis of an adult thyroid gives a percentage of 82.24 of water, 17.66 of organic and 0.1 of inorganic constituents; in that of an infant the figures were, 77.21, 22.35, and 0.44 respectively. Like the spleen, it is alkaline during life and acid after death, the acidity being due to the same cause—the formation of sarcolactic acid. Fatty acids, xanthin, hypoxanthin, and other extractives have also been obtained from it.

The constituents which possess the greatest importance are those of a proteid nature, for upon them it is believed depend some of the remarkable powers with which this gland is endowed. Among these are *thyreoproteid* and *thyreo-antitoxin* ( $C_8H_{11}N_3O_8$ ). A substance has also been found in the thyroid, principally combined with a proteid, although also free, called *thyro-iodin* and *iodo-thyrin*, containing 9.3 per cent. of iodin and 0.56 per cent. of phosphorus. The amount of iodin in each gram of the human adult thyroid varies from 0.3 to 0.9.

**Structure.**—The thyroid has a capsule of connective tissue which sends off septa or *trabeculae* that enclose the *thyroid vesicles*

of follicle.  
ve tissue.  
lum of follicle.

FIG. 183.—From section through thyroid gland of child (Böhm and Davidoff).

(Fig. 183), each of which is lined by cubical epithelium and contains viscid, *colloid* liquid, yellowish in color, which is coagulated by alcohol and stained with hematoxylin, and is doubtless secreted by these cells. Red blood-corpuscles in various stages of disintegration and white corpuscles are also found in these vesicles. The color of the colloid material is probably due to hemoglobin.

Around the vesicles is a plexus of capillary blood-vessels, which is also found between the vesicular epithelium and the endothelium of the lymph-spaces, which latter surround the vesicles and communicate with lymphatic vessels. Colloid material,

identical with that contained in the vesicles, has been found in the lymphatics.

The *arteries* which supply the thyroid body are the *superior* and *inferior thyroid*, and sometimes the *thyroidea media* or *ima*, an occasional branch of the innominate or aorta.

The nerves are from the *middle* and *inferior cervical ganglia* of the sympathetic.

**Functions.**—In recent years the physiology of the thyroid body has received a great deal of attention, and important additions have been made to the knowledge of its function by a study of (1) the effects of its disease and (2) of its removal.

**Cretinism.**—In some parts of Switzerland and elsewhere on the Continent there exists a disease characterized by a swelling of the thyroid, termed *goiter*, together with “stunted growth, swelled abdomen, wrinkled skin, wan complexion, vacant and stupid countenance, misshapen cranium, idiocy, and comparative insensibility.” This disease is *cretinism*, and those suffering from it are *cretins*. This condition is accompanied by disease of the thyroid, as manifested by the *goiter*.

**Myxedema.**—A similar condition is sometimes seen in which the striking characteristic is the appearance of the skin, which resembles *edema*; and the material which is deposited in the connective tissue was thought to be *mucin*, hence the name *myxedema*. Although there is more mucin than in ordinary connective tissue, still the material here is not altogether mucin, nor is it true edema—*i. e.*, a dropsical effusion into the cellular tissue—but a hyperplastic and modified connective tissue. In addition to this condition of the skin there is also a slowness of gait, an apathy of mind, and sometimes tremors and twitchings of muscles.

**Operative Myxedema.**—When the thyroid gland becomes enlarged, this may be due to a hypertrophy of the vesicles, *parenchymatous goiter*, or of the connective tissue, *fibroid goiter*; or the vesicles may form cysts, *cystic goiter*, or the blood-vessels may be dilated, *pulsating goiter*, or the vessels may be enlarged, and with this a prominence of the eyes, palpitation of the heart, and a quick pulse, *exophthalmic goiter* or *Graves's disease*. For goiter, one of the methods of treatment is the removal of the gland; when this is practised, a condition of *myxedema* results, *operative myxedema*. The removal of the thyroid, *thyroidectomy*, has been performed upon dogs with a fatal result in all cases, occurring so soon after the operation—within fourteen days—that the changes in the skin have no time to take place, but tremors, spasms, and convulsions occur. One remarkable fact was discovered by Schiff, who performed as many as sixty thyroidectomies on dogs—namely, that if a portion of a thyroid was, before the operation, grafted under the skin or into the peritoneal cavity, the symptoms described did not occur, and the animals did not die. Horsley removed the thyroid from monkeys, with the result of producing myxedema.

It has been demonstrated, as already stated, that grafting a thyroid or part of it into an animal before the removal of its thyroid will prevent the myxedematous symptoms. It is interesting to know that if, later, this graft is removed, the symptoms will then supervene. Injections of an extract of the thyroid gland and also feeding the gland itself are followed by the same results as the grafting process.

There are two theories which have been advanced to explain the results of removal of the thyroid: (1) autotoxication and (2) internal secretion.

*Autotoxication.*—This theory supposes that there are toxic substances normally in the blood which, being removed or rendered harmless by the thyroid, accumulate when that organ is removed and produce the effects that follow thyroidectomy. In support of this, it is stated that the urine of animals operated on is more toxic than that of unoperated animals, and that their blood is also toxic for others.

*Internal Secretion.*—We have already seen that the pancreas, in addition to the pancreatic juice, which is its external secretion, also produces an internal secretion. This is also believed to be true of the thyroid, and it is this secretion which is taken up by the blood or the lymph in its passage through the gland and carried to the tissues, where it is, in some way not understood, connected with their metabolic processes. From the disturbances in the nervous system and connective tissues which occur on ablation of the gland, it is probably especially related to their metabolism. When, therefore, after extirpation of the thyroid or in cases of myxedema where the gland is diseased, injections of the extract or injections of the gland itself are followed by beneficial results, it is, doubtless, due to the introduction into the blood of this internal secretion. It is also possible that some of the toxic products of metabolism may be destroyed by the gland or its secretion.

Several observers have maintained that the thyroid was intimately connected with the regulation of the supply of blood to the head, and have reasoned thus from its great vascularity and direct connection with the blood-vessels of the head; and Cyon has demonstrated that the nerves supplying the thyroid when stimulated lower the blood-pressure in the carotid, by virtue of vasodilators, which are contained in the trunks of the nerves. These nerves are called into action when the cut ends of the vagi, of the depressors, or of the cardiac branches of the recurrent laryngeal nerves are stimulated.

To which of the constituents of the thyroid extract its effects are due is still a mooted question. Indeed, the most recent researches seem to indicate that the gland forms more than one substance, each one having its own action; thus there seems to be no doubt that both iodothylin and thyreo-antitoxin are produced,



although at the present time the iodothylin seems to be regarded as the most active ingredient.

Thyroid extract has also been recommended as a means of treating obesity, on the ground that it increases metabolism; there is undoubtedly a diminution of fat in its use.

The thyroid gland has been used in the treatment of goiter, myxedema, etc., in various ways. Thus Schiff and Esselsberg, in 1884, made grafts both in the abdominal cavity and in the cellular tissue. Birch, on the advice of Horsley, transplanted the thyroid of a sheep into the peritoneal cavity of a woman suffering with myxedema. For a time she was benefited, but the gland was absorbed and the symptoms returned. In 1890 Pisenti extracted the juice from the thyroid and injected it into the tissues; Gley was the first to use this method on the human subject and cured his patient. Horwitz, in 1892, demonstrated that the gland itself could be given by the mouth with equally good results as when its extract was injected, and later the extract was given by the mouth. At the present time tablets containing the fresh gland of the sheep are used for goiter, myxedema, obesity, etc.

H. O. Nicholson reports the case of a child cretin in which the effects of *thyroid treatment* upon the bodily and mental condition were remarkably rapid and complete. At the age of two years and eight months the child was in the condition of well-marked cretinism. The initial dose of thyroid powder was  $2\frac{1}{2}$  grains, once daily; but after three days, on account of diarrhea, this was reduced to  $1\frac{1}{4}$  grains for several weeks, when the original dose was given. After four months of treatment a photograph, with which the article is illustrated, showed "a bright, happy, pretty child, to all appearances normal, both physically and mentally" (Figs. 184, 185). A few months later death occurred during a malignant attack of measles, but an autopsy could not be obtained. In the etiology the author lays stress on the fact that the child seemed normal for the first four months of life, at the end of which it contracted whooping-cough lasting four months, and then it was seen to be abnormal. He attributes the origin of cretinism to the attack of pertussis.

We are indebted to M. A. Flourens, of Bordeaux, for a very interesting *résumé* of *thyroid medication*, and the following case is taken from his pamphlet:

This was a girl of twelve years, suffering from myxedema, in whom there was a question as to the presence of a thyroid. She came under treatment in February, 1893. The disease began when she was nine years old.

The child began to be inattentive, flighty, and especially indifferent. Her memory became weakened and study fatiguing. She developed a state of torpor and did not care to play with her brother and sister. Her movements were slow and lazy, a laziness more moral than physical, especially of the will, for if compelled



to move she could take walks as long as 10 kilometers without much effort. At the same time her disposition changed, became "sour," and everything annoyed her. In endeavoring to counteract the feeling of cold that the warmest clothing would not allay, she would sit near enough to the open hearth to burn her limbs.

These signs of intellectual apathy were accompanied by physical symptoms. The skin became pale and the face swollen, losing its oval shape and assuming the aspect of a full moon, symptoms so well described by Gull in his first observations. The swelling extended to the limbs and body, becoming hard and resisting, not

FIGS. 184, 185.—Illustrating Nicholson's article on thyroid treatment in a cretin (*Arch. of Ped.*, June, 1900). Fig. 184, before treatment; Fig. 185, after treatment.

presenting the characteristic pitting of edema. The skin lost its softness and the trunk and limbs were affected with ichthyosis. The hair remained long and silky. There was no change in the nails. The development of the teeth was arrested, these being short, as if buried in fungous gums from which emerged only the extremities of teeth. This was more noticeable in the superior maxilla. The child was weighed but, unfortunately, the exact figures were lost. They were, however, very high for a child of her age. Since two years there has been a complete arrest of growth. Her height was about 4 feet 2½ inches.

The report of her condition in October, 1894, was as follows : The treatment was continued and the amelioration persisted. The edema completely disappeared, the teeth had grown, and there was no longer the spongy condition of the gums of the superior maxilla. The intellectual torpor had disappeared, and the child was more lively ; she answered intelligently when interrogated ; she no longer had the sensation of cold. She had grown considerably. In October, 1895, the menses appeared, the general condition was excellent, and the memory had returned.

Figs. 186 and 187 show a case of goiter which was treated with thyroid extract.

FIGS. 186, 187.—Case of goiter before and after treatment with thyroid extract (Flourens).

**Parathyroids.**—These are four small glandular bodies situated one on the lateral and one on the mesial surface of each lobe of the thyroid. They consist of columns of granular epithelium, with vascular connective tissue between the columns. It is claimed by some that after removal of the thyroid these bodies become hypertrophied and perform its functions, and it has been supposed that when after thyroidectomy the usual results do not appear it is due either to the fact that some of the thyroid was left, or else that these parathyroids took up its functions ; this is Gley's explanation in the case of rabbits, in which ablation of the thyroid

is usually followed by negative results; and he states that if the parathyroids are removed from these animals together with the thyroid, the usual results appear. On the other hand, Blumenreich and Jacoby state that it makes no difference whether the parathyroids are included or excluded.

### THE THYMUS.

The thymus is situated behind the sternum, and extends from the fourth costal cartilage to the lower border of the thyroid. It is about 5 cm. long, about 4 cm. broad, and 1 cm. thick, and at birth weighs about 16 grams.

The thymus reaches its full size at the end of the second year, at which time it decreases, and at puberty it has almost wholly dis-

FIG. 188.—A small lobule from the thymus of a child, with well-developed cortex, presenting a structure similar to that of the cortex of a lymph-gland: a, hilus; b, medullary substance; c, cortical substance; d, trabecula;  $\times 60$  (Böhm and Davidoff..

appeared; it is, therefore, a temporary organ. The thymus of the calf is called the *neck* or *throat-sweetbread*, while the pancreas is the *belly-sweetbread*.

**Chemical Composition.**—The reaction during life is alkaline, but acid after death, due to sarcolactic acid. It contains 12.29 per cent. of proteids, together with adenin, xanthin, hypoxanthin, and guanin. Iodin exists also in the gland.

**Structure.**—The thymus is composed of two lobes, sometimes united into one and sometimes separated by an intermediate lobe. It presents an irregular lobulated appearance, and has an external *capsule*, beneath which are the *lobules*, separated from one another by connective tissue, in which are the blood-vessels and lymphatics. Each lobule is made up of a *cortex* and *medulla*; the cortex being composed of *nodules* separated by *trabeculae*, as described in connection with the lymphatic glands (p. 332). In the nodules are *lymphoid cells* and a *reticulum* (Fig. 188). In the medullary portion the lymph-corpuscles are less numerous, but there are here

peculiar cells, the *concentric corpuscles of Hassal* (Fig. 189), which consist of a central cell around which flattened epithelial cells are arranged concentrically.

The arteries which supply this gland are derived from the internal mammary and the superior and inferior thyroid. The nerves are from the pneumogastric and sympathetic.

**Function.**—Together with other glands containing lymphoid tissue, the thymus is undoubtedly a source of leukocytes; and because Watney has found in cells of the thymus hemoglobin varying in shape from granules to masses having the appearance of red blood-corpuscles, and similar cells in the lymph coming from the gland, he concludes that the thymus is

FIG. 189.—Hassal's corpuscle and a small portion of medullary substance, showing reticulum and cells, from thymus of a child ten days old (Huber).

one of the sources of red blood-corpuscles. So far as known, no effects are produced by injecting into the tissue an extract of the thymus, nor by injecting portions of the gland itself.

## THE SUPRARENAL CAPSULES OR ADRENAL BODIES.

These are flattened, glandular structures situated one above and one in front of the upper part of each kidney. In length each is about 3.5 cm., in width 2.5 cm., and in thickness 1 cm., the right being smaller than the left. They present a *cocked-hat* appearance. The weight of each is about 4 grams.

**Chemical Composition.**—These bodies contain proteids, cell-globulin and nucleoproteid, extractives such as occur in the other ductless glands, salts, of which one is potassium phosphate, hippuric and taurocholic acids. The presence of a reducing substance similar to jecorin of the liver has been claimed by some, but denied by others.

**Structure.**—There is a marked difference between the structure of the suprarenal capsules and the other ductless glands which we have considered. Each capsule is invested with a fibrous capsule. On section (Fig. 190) it is found to consist of a *cortical portion* or *cortex*, the greater part of the gland, which is yellow in color and presents a striated appearance; and a *medullary portion* or *medulla*, which is of a dark-brown or dark-red color. The capsule gives off septa, which so divide the cortex as to leave spaces, filled with granular, polyhedral cells, some of them containing oil-

globules, each cell being provided with a nucleus. Just beneath the capsule these cells form the *zona glomerulosa* and *zona fasciculata*, and still deeper, the *zona reticularis*.

In the medulla the fibrous stroma is arranged so as to form bundles around the veins, which are very numerous in this portion of the gland. In the spaces are irregular, granular cells, some

Capsule.

*Zona glomerulosa.*

*Zona fasciculata.*

*Zona reticularis.*

FIG. 190.—Section of suprarenal cortex of dog;  $\times 120$  (Böhm and Davidoff).

of which are branched; these are stained brown by chromic acid, and the material taking the stain is called a *chromogen*.

The arteries supplying the suprarenal capsules are derived from the aorta, phrenic, and renal, and break up into capillaries in the septa of the cortical portion, which discharges its veins in the medulla, finally becoming the suprarenal vein, which on the right side enters the inferior vena cava, and on the left the renal vein. The nerves are derived from the solar and renal plexuses,

and from the phrenic and pneumogastric, and upon these there are ganglia.

**Functions.**—*Addison's disease* is defined as "a disease marked by a peculiar bronze-like pigmentation of the skin, early and severe prostration, and progressive anemia, and usually ending fatally. It is due to tubercular disease of the suprarenal capsules."

In 1855 Addison discovered the connection of the disease above described with pathologic changes in the suprarenal bodies, and removal of both of them experimentally by Brown-Séquard produced a similar condition, excepting the discoloration of the skin, and a fatal result, usually within twelve hours. It was surmised that the absence of pigmentation was due to the speedy death. Since then the capsules have been crushed, with the effect of producing the skin changes. Within recent years the suprarenal capsules have been frequently removed, always with a fatal result within three days, and the blood of such animals when injected into other animals whose capsules have been removed is toxic, while if normal blood is injected into the veins of the latter their life is prolonged. It is supposed from this that the function of the suprarenal capsule is to destroy some toxic substance in the blood; this accumulates when these bodies are removed, and such blood is poisonous. This is the *autotoxication* theory.

Schäfer has injected into animals watery and glycerin extracts of the capsules, the results varying with the amount injected and the animal experimented upon. In the cat and dog large doses produce quickened and augmented heart-beat, shallow and rapid respiration, and fall of temperature. Intravenous injection of suprarenal extract produces, according to Schäfer, a powerful physiologic action upon the muscular system in general, greatly prolonging the contraction of a muscle in response to a single excitation of its nerve (Fig. 191), but especially upon the muscular walls of the blood-vessels and heart. A certain amount of action is also manifested upon some of the nerve-centers in the bulb, especially in the cardio-inhibitory center, and to a less extent upon the respiratory center. The blood-pressure is greatly increased, due to contraction of the arterioles, the extract acting upon the muscular coat of these vessels directly, and not through the vasomotor center.

The active principle which produces these physiologic effects is obtained from the medulla, and it has been demonstrated that so small an amount as  $\frac{1}{1000000}$  part of a gram per kilo of body-weight, equivalent to  $\frac{1}{13000}$  gram for an adult man, will produce distinct physiologic results upon the heart and arteries; but whether it is the alkaloidal substance, *epinephrin*, isolated by Abel, or the crystallizable one obtained by Takamine and called *adrenalin*, has not yet been determined.

Schäfer draws the following conclusions: "It may be consid-

ered probable that the suprarenal capsules are continually secreting into the blood an active material, which although present in that fluid only in minute quantities, may yet be sufficient to produce very distinct effects upon the metabolic processes of muscular tissue, and especially the muscular tissue of the vascular system. It has, in fact, been stated by Cybulski, and this statement has been confirmed by Langlois and by Biedl, that the blood of the suprarenal vein contains a sufficient amount of the active principle of suprarenal extract to produce a marked rise of blood-pressure when intravenously injected. I have, in spite of careful experiments, not been able to confirm this statement. Nor is it easy to understand how it can be true, since such blood is constantly flowing into the vena cava in larger quantity than these observers

FIG. 191.—Effect of suprarenal extract upon muscle-contraction in the frog: *A*, normal muscle-curve of gastrocnemius; *B*, curve taken during suprarenal poisoning, but otherwise under the same conditions as *A*; time tracing; 100 per second (Schäfer).

injected. But whether we are able to show it experimentally or not, there is very little doubt of the fact that the materials found pass somehow or other into the blood; and when we compare the results of suprarenal injection with the effects obtained from the removal and from disease of these organs, we can come to no other conclusion than that we have before us a notable instance of internal secretion; and that the effect of such secretion passed into the blood is beneficial to the muscular contraction and tone of the cardiac and vascular walls, and even of the skeletal muscles, appears very evident from the results both of the removal of the organs and of injection of their extracts."

Although in one case of Addison's disease in which fresh capsules of the calf were administered there was apparent benefit, the evidence is still too meager to draw any general conclusions as to its usefulness in the treatment of this affection.

## THE PINEAL GLAND.

This gland, also known as *epiphysis cerebri*, is situated in the brain behind the posterior commissure and between the anterior corpora quadrigemina. It is reddish gray in color, about 0.8 mm. long and 0.6 mm. wide, larger in childhood than in adult life, and in the female than in the male.

**Structure.**—It is composed of connective tissue and follicles lined with epithelium. In these follicles is a viscid fluid with *brain-sand*, *acervulus cerebri*, which consists of calcium phosphate and carbonate, magnesium and ammonium phosphate, with some organic matter. The pineal gland exists in the fetal brain in the form of a hollow protrusion from the posterior part of the roof of the interbrain. It is regarded by some as an atrophied third eye. Schäfer says that in the chameleon and some other reptiles the pineal gland is better developed, and is connected with a rudimentary median eye of invertebrate type, placed upon the upper surface of the head.

Its function is unknown.

## THE PITUITARY BODY.

This body is also known as *hypophysis cerebri*. It is situated on the sella Turcica of the sphenoid bone, is reddish gray in color, and weighs from 4 dgm. to 8 dgm.

**Structure.**—It consists of two lobes, the *anterior* being the larger. This lobe is developed as a hollow or tubular prolongation of the epiblast of the buccal cavity, and consists of vesicles and alveoli lined with columnar epithelium, which is in some places ciliated. In the alveoli is sometimes found a colloid substance similar to that in the thyroid, and around the alveoli are lymphatics and capillaries. Indeed, the resemblance in structure between the pituitary body and the thyroid has led to the supposition that physiologically they are related.

The *posterior* lobe has a different origin from the anterior. It is developed from the floor of the third ventricle, and in fetal life communicates with this cavity through the infundibulum. It consists in the adult principally of vascular connective tissue, containing but few nervous elements.

**Function.**—The pituitary body has been repeatedly removed from dogs and cats, death resulting within two weeks. The symptoms following removal are (1) diminution of body-temperature; (2) loss of appetite and lassitude; (3) muscular twitchings, tremors, and spasms; (4) dyspnea. Some of these symptoms are improved by injections of extract of the pituitary body. It will be remembered that some of these symptoms occurred after ablation of the thyroid (p. 341), and it is stated that the pituitary body becomes enlarged after thyroidectomy. Rogowitsch thinks



that this accounts for the failure to produce fatal results in rabbits by the removal of the thyroid, the pituitary body being especially well developed in that animal. It is stated by some that *acromegaly*, a disease characterized by hypertrophy of the bones of the face and extremities, and also of the skin, is associated with enlargement and degeneration of the pituitary body. Dr. Kinnicutt states that in 34 recorded cases of acromegaly, with full autopsy, a microscopic lesion of the pituitary body has been found in every instance, and in the majority of cases it has proved to be either a simple hyperplasia or a tumor growth of some kind. Others have not found these lesions in cases of enlargement of the gland, but rather a persistence of the thymus.

There seems to be no valid reason for concluding that the thyroid and the pituitary body have any physiologic relation with each other. Injections of extracts of the pituitary body cause great increase in the force of the heart's beat, and also an increase in blood-pressure by contracting the arterioles; that of the thyroid does neither.

That the pituitary body furnishes an internal secretion seems to be beyond question, and this has the effect of increasing the contraction of the heart and arteries, and also of influencing the metabolism of the bones and nervous system, but just how this is brought about is not determined.

#### THE CAROTID AND THE COCCYGEAL GLANDS.

The *carotid gland* is situated at the bifurcation of the common carotid artery, and the *coccygeal gland* or *Luschka's gland* is situated in front of the tip of the coccyx, just above the attachment of the sphincter ani. These glands are collections of small arteries enclosed in granular polyhedral cells, the whole being enclosed in a capsule. Into the coccygeal gland sympathetic nerves pass. Macalister regards it as consisting of "the condensed and convoluted metameric dorsal arteries of the caudal segments embedded in tissue which is possibly a small persisting fragment of the neurenteric canal."

The function of these glands is unknown, if, indeed, they possess any.

#### RESPIRATION.

One of the most important processes carried on in the body is that by which the tissues receive oxygen. In animals whose structure is exceedingly simple, and so constituted that all portions of their bodies are bathed by the oxygen-carrying medium, the oxygen is directly absorbed; but in those in which there are tissues remotely situated as regards this medium, some provision must be made for conveying the oxygen from the medium to the

tissues. This condition exists in man, many of whose tissues are so deeply situated that without such provision the maintenance of life would be impossible. In man this medium is the blood. But additional provision must be made for the renewal of the oxygen abstracted by the tissues. That part of the process by which the tissues take oxygen from the blood is *internal respiration*, and that part by which the renewal is accomplished is *external respiration*. Ordinarily, when respiration is spoken of without qualification it is external respiration that is referred to.

**Respiratory Apparatus.**—The group of organs concerned in external respiration is collectively spoken of as the *respiratory apparatus*, which consists of the nose, larynx, trachea, bronchi, lungs, and thorax.

### THE NOSE.

The nose is the beginning of the air-passages, for although it is regarded by many as the organ of smell only, it has another function as well. The mouth belongs to the alimentary canal, and should be opened only to take in food or to speak, never to take in air. The proper channel for the admission of air is the nose, and the use of the mouth for this purpose is not physiologic. Indeed, man is said to be the only animal that breathes through the mouth. If the nursing child should attempt to use its mouth for the admission of air to the lungs, sucking could not be performed without great difficulty, and after a few moments the child would be compelled to let go the breast in order not to suffocate.

**Mouth-breathing.**—There is no more pernicious habit, so far as health is concerned, than breathing through the mouth. If this is due to habit and to nothing else, it may be overcome; but if, as is often the case, it is due to some diseased condition of the nose, or to the presence in the nasal cavities of tumors, or to the existence of enlarged tonsils, its relief can be accomplished only by surgical means. The function of the nose in respiration is to warm the air and to filter out from it dust and other extraneous matter which would otherwise enter the air-passages and cause irritation. When air is taken in by the mouth these beneficial results do not occur.

Mouth-breathing causes dryness of the mouth and the pharynx, which condition is very noticeable on awaking from sleep. The mucous membrane becomes congested and inflammation is likely to follow. A chronic inflammatory condition of the larynx may also result from this cause, and the evidence is very conclusive that the hearing becomes affected in these cases. The deformity known as *pigeon-breast* is not an uncommon sequel. Indeed, the consequences of mouth-breathing are numerous, widespread, and serious, and the subject has never received the attention which its importance demands.

## THE LARYNX.

This organ (Figs. 192, 193) is situated at the upper part of the neck, behind and below the base of the tongue. It is composed of nine cartilages, which are connected by ligaments.

**Cartilages.**—These are the thyroid, cricoid, arytenoid (two), cornicula laryngis (two), cuneiform (two), and epiglottis.

The **thyroid** is the largest of all the laryngeal cartilages, and the angle of its two *alæ* forms the prominence in the front of the throat, *Adam's apple* or *pomum Adami*.

FIG. 192.—Articulations and ligaments of the larynx, anterior view: *A*, hyoid bone, with *a* its greater, and *a'* its lesser cornua; 1-5, ligaments; 6, lateral cricothyroid articulation; 7, junction of cricoid and trachea (Testut).

FIG. 193.—Articulations and ligaments of the larynx, posterior view: *A*, hyoid; *B*, thyroid, with *b* and *b'* its cornua; *C*, cricoid; *D*, arytenoids; *E*, cartilages of Santorini; *F*, epiglottis; *G*, trachea; 1-6, ligaments; 2, opening for superior laryngeal artery; 7, junction of trachea and cricoid (Testut).

The **cricoid** is ring-shaped. The **arytenoids** articulate with the cricoid cartilage, while to the summit of these are attached the **cornicula laryngis** or *cartilages of Santorini*.

The **cuneiform cartilages** or *cartilages of Wrisberg* are two small bodies, one in each fold of the mucous membrane extending from the apex of the arytenoid to the epiglottis, the *aryteno-epiglottic fold*.

The **epiglottis** is behind the tongue, in front of the opening of the larynx. Its position is vertical during respiration, but during

a part of the act of deglutition it is carried backward and closes the laryngeal opening.

The cartilages of the larynx are hyaline, except the cornicula laryngis, cuneiform, and epiglottis, which consist of yellow fibro-cartilage, and, being hyaline, do not become calcified.

**Muscles.**—Of these there are two sets—*extrinsic*, which arise outside the larynx, and *intrinsic*, which arise within the larynx and are also inserted within it.

**Extrinsic Muscles.**—These may be subdivided into the *depressors* and *elevators* and exist in pairs.

The *depressor* muscles of the larynx and hyoid bone are : *Sternohyoid*, which arises from the clavicle and sternum, and is inserted into the hyoid bone ; *sternothyroid*, which arises from the sternum and cartilage of the first rib, and is inserted into the ala of the



FIG. 184.—Diagram to illustrate the thyro-arytenoid muscles; the figure represents a transverse section of the larynx through the bases of the arytenoid cartilages: *Ary*, arytenoid cartilage ; *p.m.*, processus muscularis ; *p.v.*, processus vocalis ; *Th*, thyroid cartilage ; *c.v.*, vocal cords ; *Oe* is placed in the esophagus ; *m.thy.ar.i.*, internal thyro-arytenoid muscle ; *m.thy.ar.e.*, external thyro-arytenoid muscle ; *m.thy.ar.ep.*, part of the thyro-ary-epiglottic muscle, cut more or less transversely ; *m.ar.t.*, transverse arytenoid muscle (redrawn from Foster).

thyroid cartilage ; *thyrohyoid*, which appears like a continuation of the sternothyroid, and arises from the side of the thyroid and is inserted into the hyoid bone ; *omohyoid*, which arises from the upper border of the scapula and is inserted into the hyoid bone.

The *action* of this group of muscles is to depress the larynx and hyoid bone at the close of deglutition ; these structures having previously been drawn up with the pharynx. The omohyoid by carrying the hyoid backward, as well as depressing it, aids in performing the act of sucking. The thyrohyoid raises the thyroid cartilage as well as depresses the hyoid bone.

The *elevators* of the larynx and hyoid bone are the *digastric*, which arises from the mastoid process of the temporal bone and from near the symphysis of the lower jaw, and is attached to the hyoid bone by a fibrous loop ; *stylohyoid*, which arises from the styloid process of the temporal bone, and is inserted into the hyoid ; *mylohyoid*, which arises from the mylohyoid ridge of

the lower jaw, and is inserted into the hyoid bone; and *genio-hyoid*, which arises from the inferior genial tubercle of the lower jaw, and is inserted into the hyoid bone.

The *action* of this group of muscles is to raise the hyoid bone and the larynx during deglutition; or if the hyoid bone is depressed and fixed, their contraction depresses the lower jaw.

**Intrinsic Muscles** (Figs. 194, 195).—These are eight in number:

(1) *Cricothyroid*.—This muscle arises from the front and side of the cricoid cartilage, and is inserted into the lower border of the thyroid and the anterior border of the lower cornua. The *action* of the two muscles is to make tense and elongate the vocal cords. Their action will be better understood after a consideration of the thyrohyoid muscles.

(2) *Crico-arytenoideus Posticus*.—It arises from the posterior surface of the cricoid, and is inserted into the muscular process of the base of the arytenoid. The *action* of the two muscles is to rotate outward the arytenoid cartilages, and thus separate and make tense the vocal cords and open the glottis.

(3) *Crico-arytenoideus Lateralis*.—This muscle has its origin from the upper border of the side of the cricoid cartilage, and is inserted into the muscular process of the arytenoid. The *action* of the pair of muscles is to rotate the arytenoid

FIG. 195.—Larynx and its lateral muscles after removal of the left plate of the thyroid cartilage: 1, thyroid cartilage; 2, thyro-epiglottic muscle; 3, cartilage of Wrisberg; 4, ary-epiglottic muscle; 5, cartilage of Santorini; 6, oblique arytenoid muscles; 7, thyro-arytenoid muscle; 8, transverse arytenoid muscle; 9, processus muscularis of arytenoid cartilage; 10, lateral crico-arytenoid muscle; 11, posterior crico-arytenoid muscle; 12, cricothyroid membrane; 13, cricoid cartilage; 14, attachment of cricothyroid muscle; 15, articular surface for the inferior cornu of the thyroid cartilage; 16, cricotracheal ligament; 17, cartilages of trachea; 18, membranous part of trachea (Stoerk).

cartilages inward, approximating the vocal cords and closing the glottis.

(4) *Arytenoideus*.—This is a single muscle and arises from the posterior surface and outer border of one arytenoid cartilage, and is inserted into the same parts of the other arytenoid. Its *action* is to approximate the arytenoid cartilages and close the glottis, especially at the posterior portion.

(5) *Thyro-arytenoideus*.—This muscle arises from the angle of the thyroid and the cricothyroid membrane, and is inserted into the arytenoid cartilage. It consists of two portions, or *fasciculi*: An *inner*, which is inserted into the vocal process of the arytenoid and is adherent to the true vocal cord; and an *outer* portion, which is inserted into the muscular process. The *action* of the two muscles as a whole is to draw the arytenoid cartilages toward the thyroid, shortening and relaxing the vocal cords; the inner fasciculus acting alone modifies the elasticity and tension of the vocal cords, while the outer rotates the arytenoid cartilages inward and approximates the cords.

(6) *Thyro-epiglottideus*.—It arises from the angle of the thyroid

1

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FIG. 198.—The laryngoscopic image in easy breathing: 1, base of the tongue; 2, median glosso-epiglottic ligament; 3, vallecule; 4, lateral glosso-epiglottic ligament; 5, epiglottis; 6, cushion of epiglottis; 7, cornu major of hyoid bone; 8, ventricular band, or false vocal cord; 9, true vocal cord; opening of the ventricle of Morgagni seen between 8 and 9; 10, folds of mucous membrane; 11, sinus pyriformis; 12, cartilage of Wrisberg; 13, aryteno-epiglottic fold; 14, rima glottidis; 15, arytenoid cartilage; 16, cartilage of Santorini; 17, posterior wall of pharynx (Stoerk).

cartilage, and is inserted into the aryteno-epiglottic fold and the margin of the epiglottis. The *action* of these muscles is to depress the epiglottis, and, by virtue of some of the fibers which spread out upon the outer surface of the *sacculus laryngis*, to compress it.

(7) *Aryteno-epiglottideus Superior*.—This arises from the apex of the arytenoid, and its fibers disappear in the aryteno-epiglottic fold. The *action* of the pair is to constrict the opening of the larynx during deglutition.

(8) *Aryteno-epiglottideus Inferior*.—This muscle also arises from the arytenoid, and spreads out upon the inner surface of the *sacculus laryngis*, and the *action* of the pair is to compress the *sacculus*.

Gray, to whom we are indebted for the description of the

larynx and other anatomic structures, in considering the action of these muscles, says that they may be conveniently divided into two groups, viz., 1. Those which open and close the glottis; 2. Those which regulate the degree of tension of the vocal cords.

1. The muscles which open the glottis are the crico-arytenoidei postici, and those which close it are the arytenoideus and the crico-

arytenoidei laterales. 2. The muscles which regulate the tension of the vocal cords are the crico-thyroidei, which tense and elongate them; and the thyro-arytenoidei, which relax and shorten them. The thyro-epiglottideus is a depressor of the epiglottis, and the aryteno-epiglottidei constrict the superior aperture of the larynx, compress the sacculi laryngis, and empty them of their contents.

**Interior.**—If the larynx is inspected from above, looking downward (Fig. 196), it will be seen that its opening is bounded in front by the *epiglottis*, behind by the *interarytenoid* fold, consisting of mucous membrane, connecting the arytenoid cartilages, and the *aryteno-epiglottic folds*, also mucous membrane, which connect the sides of the epiglottis and the arytenoid cartilages. The cartilages of Santorini and Wrisberg make prominences in these folds.

The *cavity* of the larynx (Fig. 197) extends from its opening to the lower border of the cricoid cartilage. In looking into it there will be seen the *inferior* or *true vocal cords*,

FIG. 197.—Vertical transverse section of the larynx: 1, posterior face of epiglottis, with 1', its cushion; 2, aryteno-epiglottic fold; 3, ventricular band, or false vocal cord; 4, true vocal cord; 5, central fossa of Merkel; 6, ventricle of larynx, with 6', its ascending pouch; 7, anterior portion of cricoid; 8, section of cricoid; 9, thyroid cut surface; 10, thyrohyoid membrane; 11, thyrohyoid muscle; 12, aryteno-epiglottic muscle; 13, thyro-arytenoid muscle, with 13', its inner division, contained in the vocal cord; 14, cricothyroid muscle; 15, subglottic portion of larynx; 16, cavity of the trachea (after Testut).

vocal bands or ligaments, the portions which approximate the most closely, and between them a space or fissure, the *glottis* or *rima glottidis*. The term *rima glottidis* is applied by some authors to the boundary of the space, and by others to the space itself, using it synonymously with *glottis*. Above the true vocal cords are the *superior* or *false vocal cords*, and between the true and false on

each side is the *ventricle of Morgagni*, the anterior part of which connects with the *sacculus laryngis*, or *laryngeal pouch*, into

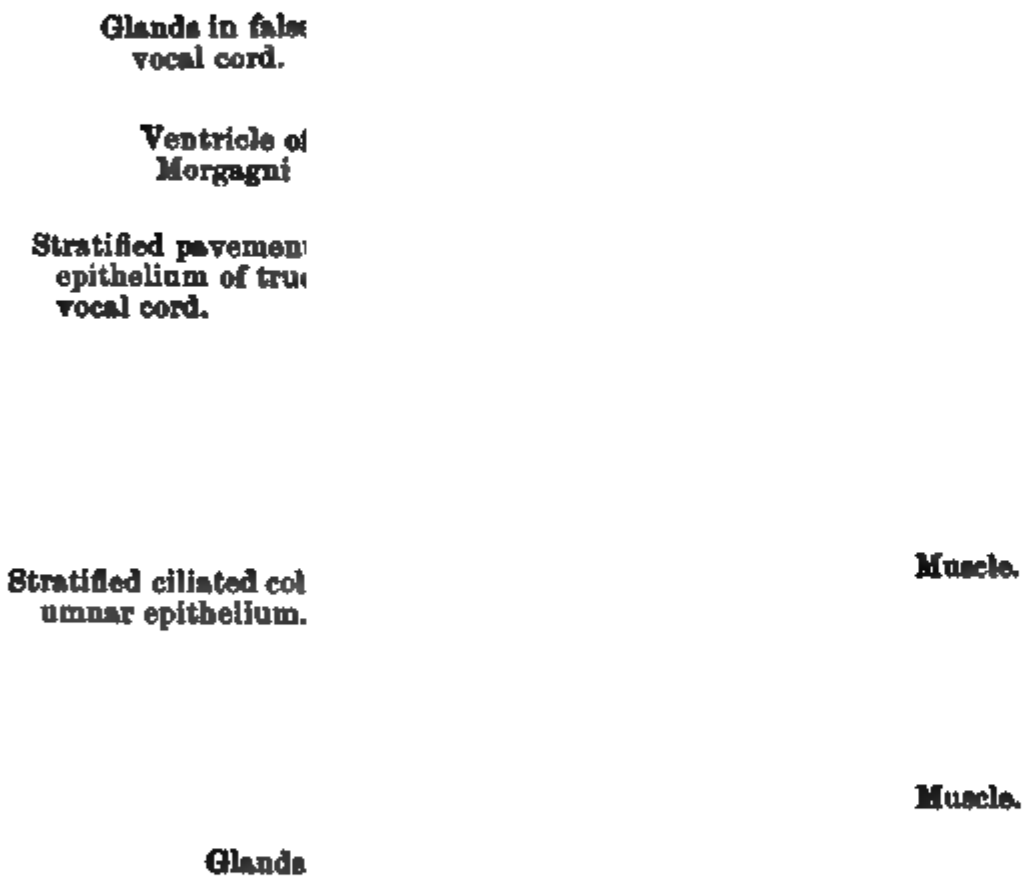


FIG. 198.—Vertical section through the mucous membrane of the human larynx;  $\times 5$  (Böhm and Davidoff).

which discharge 60 or 70 glands situated in the submucous areolar tissue.



The glottis and the true vocal cords demand a somewhat more detailed description than given above, owing to their importance in connection with respiration and phonation.

**Glottis** (Figs. 194-196, 199-201).—This opening differs in shape under different conditions. Its length from the angle of the true vocal cords in front to the vocal processes of the arytenoid cartilages behind is about 2.5 cm., and its breadth when dilated varies from 0.8 cm. to 1.2 cm. During ordinary inspiration its breadth increases, becoming triangular, and in very deep or forced



FIG. 199.—The voicing (female) larynx: *A*, small or highest register; *B*, upper thin or middle register; *C*, lower thin or middle register; *T, T*, tongue; *P, P*, false vocal cords; *S, S*, cartilages of Santorini; *W, W*, cartilages of Wrisberg; *V, V*, vocal cords (after Browne and Behnke).

inspiration lozenge-shaped, while during phonation the vocal cords are more approximated than at the end of respiration.



FIG. 200.—The larynx in gentle breathing: *L*, epiglottis; *V*, vocal cords; *S*, cartilages of Santorini, which surmount the arytenoid cartilages; *P, P*, ventricular bands (Lennox-Browne).

FIG. 201.—The larynx in deep breathing: *WP*, tracheal rings; *B*, openings of bronchi; *P, P*, ventricular bands (Lennox-Browne).

The changes which take place during voice-production are more fully considered in connection with that function of the larynx (p. 389).

**True Vocal Cords.**—These are called also vocal bands and vocal ligaments. They consist of strong fibrous bands covered with mucous membrane, and parallel with them and attached to them are the inner portions of the thyro-arytenoid muscles.

The *mucous membrane* lines the entire larynx, and forms the folds already described. Below the false vocal cords it is covered with columnar ciliated epithelium. Above these cords cilia are only found in front up to the middle of the epiglottis. Elsewhere, including the true cords, the epithelium is stratified.

**Vessels and Nerves.**—The **arteries** which supply the larynx are derived from the superior and inferior thyroid. The **nerves** are

the superior laryngeal, a branch of the *vagus*, which supplies the mucous membrane, the cricothyroid and arytenoid muscles; and the inferior laryngeal, or recurrent laryngeal, also a branch of the *vagus*, which supplies all the other muscles, and also the arytenoid muscle.

### THE TRACHEA.

The *trachea* or *windpipe* (Fig. 202) is about 11 cm. in length, and 2.5 cm. in diameter, and extends from the cricoid cartilage to its division into the *bronchi*, which corresponds to the fourth or fifth dorsal vertebra.

**Structure.**—It is composed of rings of cartilage, from 16 to 20 in number, which are incomplete behind, where the trachea is in contact with the esophagus. These cartilaginous rings are situ-

FIG. 202.—From longitudinal section of human trachea, stained in orcein (Huber).

ated within the two layers of an elastic fibrous membrane. In the spaces between the rings these layers unite, thus forming a single membrane. The membrane behind is also single. Between the ends of the cartilaginous rings is also a transverse layer of unstriated muscular tissue, *trachealis muscle*, and posterior to this are some longitudinal fibers of the same kind. The trachea is lined with *mucous membrane* covered with columnar ciliated epithelium, and in it are mucous glands, *tracheal glands*, whose secretion lubricates the membrane, and there are elastic fibers arranged longitudinally.

**Blood-vessels.**—The artery supplying the trachea is the *inferior thyroid*, and its veins terminate in the *thyroid venous plexus*.

**Nerves.**—The nerves are branches of the *vagus* and *sympathetic*.

## THE BRONCHI.

These are two in number : the **right bronchus**, which is more horizontal than the left and is about 2.5 cm. in length, divides into three subdivisions which go to the right lung, which has three lobes. The **left bronchus** is about 5 cm. long, and divides into two branches, one for the upper, and the other for the lower lobe of the left lung. The bronchi are, like the trachea, made up of cartilaginous rings or plates with intervening membrane.

## THE LUNGS.

There are two lungs, **right** and **left**, situated in corresponding sides of the thorax ; each being divided by fissures into lobes—the right into three, *superior, middle, and inferior*, and the left into two, *superior and inferior*. The *root* of the lung, where this organ is connected with the heart and trachea, is composed of *bronchus, pulmonary artery, pulmonary veins, bronchial arteries, bronchial veins, pulmonary plexus of nerves, lymphatics, bronchial glands, and areolar tissue*, all covered by a serous membrane—the *pleura*.

**Structure.**—Each lung is covered by the *visceral layer* of the *pleura*, beneath which is areolar tissue containing elastic fibers. This coat exists not only on the outside, but also penetrates into the interior between the lobules. The *lobules* form the *parenchyma* of the lung.

**Lobules.**—A lobule consists of a terminal or *ultimate bronchial tube* and the *air-cells* or *alveoli*, into which it opens, together with such pulmonary and bronchial vessels, lymphatics, and nerves as are associated therewith. Each lobule may be regarded as a miniature lung, a lobe being made up of many lobules. Their form and size vary, those which are on the exterior of the lung being pyramidal in shape, the base forming a polygonal figure ; while those more deeply seated present considerable variations from this.

To obtain a clearer idea of the minute structure of the lung than can be obtained from the above description, it will be profitable to approach the lobule from the direction of the bronchi.

After entering the lung the bronchi divide and subdivide into two branches, or *dichotomously*, occasionally into three. The cartilages become plates or *laminae*, between them being membrane. When the bronchial tubes become as small as 0.5 mm. the cartilage disappears and the walls are membranous ; the fibrous tissue and the longitudinal elastic fibers continue throughout, while the muscular tissue, equally extensive, is arranged around the tubes. The mucous membrane continues to be covered with ciliated epithelium of the columnar variety, until the lobule is reached. At this point each subdivision of a bronchus becomes

PLATE III.

*A*, upper bone of sternum; *B, B*, two first ribs; *C, C*, second pair of ribs; *D, D*, right and left lungs; *E*, lower end of sternum; *F, F*, right and left halves of the diaphragm in sections: the right half separating the right lung from the liver, the left half separating the left lung from the broad cardiac end of the stomach; *G, G*, eighth pair of ribs; *K, K*, ninth pair of ribs (Machse).



a lobular bronchial tube or bronchiole or ultimate bronchial tube, and on one side dilatations exist, air-cells or pulmonary alveoli.

Artery.

Lung-tissue.

Bronchiole.

FIG. 203.

Respiratory  
bronchiole.

Lung-tissue.

Alveolar duct.

FIG. 204.

FIGS. 203 and 204.—Two sections of cat's lung: Fig. 203,  $\times 52$ ; Fig. 204,  $\times 35$  (Böhm and Davidoff).

These increase in number, and, although at first limited to one side of each bronchiole, they subsequently surround the tube, and the

bronchiole becomes enlarged, forming the *atrium*, which opens into sac-like cavities, *infundibula*, each infundibulum being about 1 mm. in diameter, and these open into *air-cells* or *pulmonary alveoli*, which latter have a diameter of from 0.1 mm. to 0.3 mm.

At the infundibula the muscular tissue is less abundant and the elastic fibers are arranged around the openings of the air-cells. The epithelium in the bronchioles is both columnar ciliated and cubical non-ciliated ; but in the infundibula and alveoli it is of the pavement variety, with some cubical.

**Blood-vessels.**—Branches of the *pulmonary artery* pass into the lung with the bronchial tubes and terminate in the *pulmonary capillaries* (Fig. 205), which as plexuses lie under the mucous membrane of the walls of the infundibula and alveoli and of the partitions or *septa* between them. The capillaries have very thin

Blood-capillaries  
seen in surface  
view.

• Alveolus in cross-  
section.

FIG. 205.—Section through injected lung of rabbit (Böhm and Davidoff).

walls and a diameter of about  $8\ \mu$ , while the spaces between them are even smaller. Small veins collect the blood, and these uniting with others finally discharge into the *pulmonary veins*, which bring the blood back to the left auricle. Some of the blood brought to the lungs by the bronchial arteries returns to the venous circulation through these veins.

The *bronchial arteries*, branches of the aorta, supply the blood necessary to nourish the lung tissue, and the *bronchial veins* carry most of it back to the venous circulation, by the way of the *vena azygos major* on the right side, and by the *superior intercostal* or *left azygos vein* on the left side.

**Nerves.**—The innervation of the lungs is supplied through the pulmonary plexuses from the sympathetic and vagus. The nerves accompany the bronchial tubes.

## THE PLEURA.

The pleura is a serous membrane which covers the lung, *pleura pulmonalis* or *serous layer of the pleura*, being at its root reflected so as to line the thorax, forming the *pleura costalis* or *parietal layer of the pleura*. The theoretical space between the two layers is the *pleural cavity*. Inasmuch as these layers are normally always in contact, there is no actual space or cavity between them, although they are moistened by a small amount of secretion for lubricating purposes. When fluid collects here, as it does in some forms of *pleuritis* or inflammation of the pleura, the layers are then separated.

**Blood-vessels.**—The arteries which supply the pleura have their origin in the *intercostal*, *internal mammary*, *musculophrenic*, *thymic*, *pericardiac*, and *bronchial* arteries. The veins are similar in their anatomic relations.

**Nerves.**—The nerves are of phrenic and sympathetic origin, and accompany the branches of the bronchial artery.

## THE THORAX.

The *thorax* or *chest* is the structure which contains the lungs, heart, and great blood-vessels. The **thoracic cavity** is the space within the thorax in which these organs are located. The thorax is formed by the vertebral column and the ribs *posteriorly*, the sternum and the costal cartilages *anteriorly*, and by the ribs *laterally*. The spaces between the ribs, *intercostal spaces*, are filled by the intercostal muscles. These muscles and others which are attached to the thorax are concerned in the movements of respiration.

**Vertebral Column.**—This portion of the thorax is rigid and takes no part in any of the movements connected with respiration. The vertebræ which are concerned in the formation of the thorax are the 12 *dorsal* (Figs. 206, 207), and the anatomic points of interest are the *facets* and *demifacets* on their *bodies*, which form articulating surfaces for the *heads* of the ribs, and the *facets* on the *transverse* processes for articulation with the *tubercles* of the ribs. Between the vertebræ are *intervertebral disks* of fibrocartilage, which under the microscope present the appearance of fibrous tissue with articular cartilage (Fig. 31, page 39).

**Ribs.**—All the ribs, from the first to the twelfth, enter into the formation of the thorax, and articulate posteriorly with the vertebræ.

The first seven, the *true ribs*, are attached anteriorly to the sternum, not directly, but by means of the costal cartilages; while of the others, the *false ribs*, 3, the eighth, ninth, and tenth, are attached to the cartilage of the seventh rib, and, 2, the eleventh and twelfth, the *floating ribs*, are free at their anterior extremities.



The ribs differ very materially in their general relations; thus the upper ones are less oblique than the lower ones, the obliquity in-

creasing as far down as the ninth rib, when it becomes less (Fig. 206).

creasing as far down as the ninth rib, when it becomes less (Fig. 206).

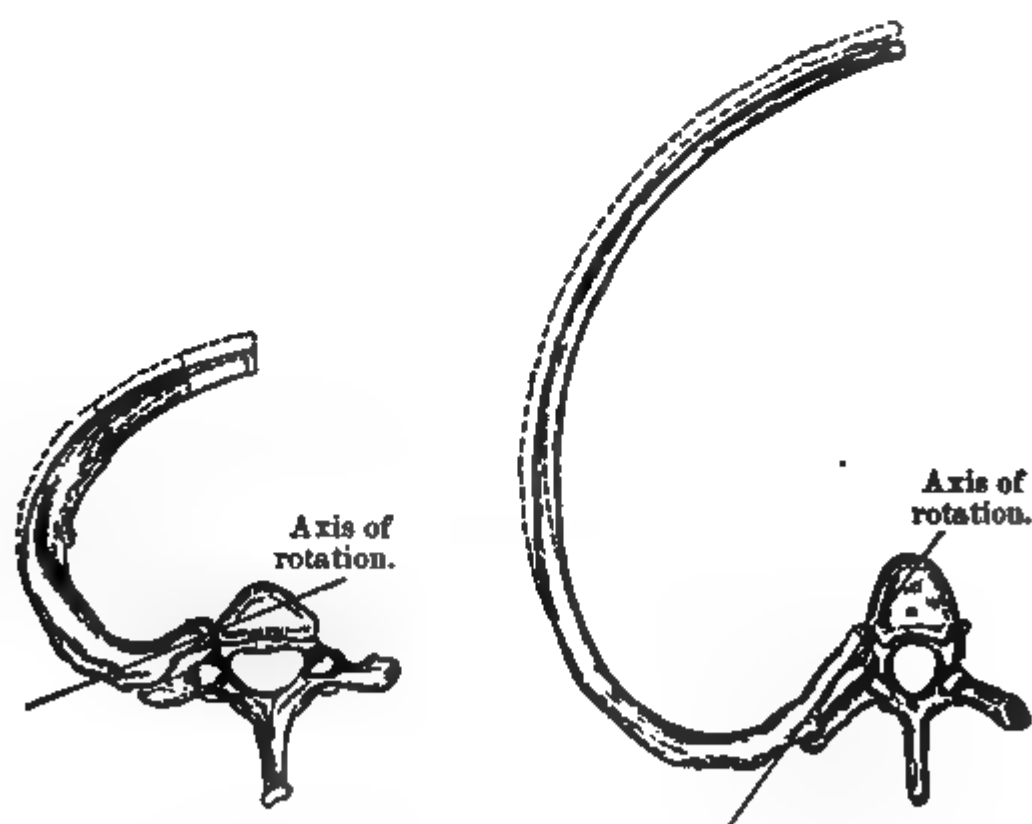


FIG. 207.—First dorsal vertebra and rib. FIG. 208.—Sixth dorsal vertebra and rib.

**Costal Cartilages.**—These are characterized by their elasticity, which is greater in early life, and in the *false* ribs than in

the true. The elasticity diminishes as years go on, until, at an advanced age, they are calcified. Rib-cartilage is not infrequently fibrous in character, and the cells are, as a rule, larger and collected into groups of greater size than those of articular cartilage (Fig. 209).

**Respiratory Muscles.**—The muscles which are concerned in the respiratory movements of the thorax may be divided into three groups: (1) Of *ordinary inspiration*; (2) of *forced inspira-*

a

Matrix.

FIG. 209.—Hyaline cartilage (costal cartilage of the ox). Alcohol preparation;  $\times 300$ . The cells are seen inclosed in their capsules. In the figure *a* are represented frequent but by no means characteristic radiate structures (Böhm and Davidoff).

*tion*; (3) of *forced expiration*. There are no muscles concerned in *ordinary expiration*.

**Muscles of Ordinary Inspiration.**—These are diaphragm, *scaleni*, external intercostals, internal intercostals (anterior portion), *levator costarum*.

**The Diaphragm.**—This forms the lower boundary of the thoracic cavity, separating it from that of the abdomen. It arises from the whole interior surface of the thorax, and the fibers which compose its muscular portion are inserted into the central or cordiform tendon. Through the diaphragm pass the vena cava, the esophagus, and the aorta.

**Nerve-supply.**—The phrenic nerves and the phrenic plexus of the sympathetic.

**Scaleni.**—The *scalenus anticus* is a muscle which arises from the anterior tubercles of the transverse processes of the third, fourth, fifth, and sixth cervical vertebræ, and is inserted into the

first rib. The *scalenus medius* arises from the posterior tubercles of the transverse processes of the cervical vertebræ from the second to the seventh, both inclusive, and is also inserted into the first rib. The *scalenus posticus* arises from the posterior tubercles of the transverse processes of the fifth, sixth, and seventh cervical vertebræ, and is inserted into the second rib.

*Nerve-supply.*—Branches of the anterior divisions of the fifth, sixth, seventh, and eighth cervical nerves. The *scalenus medius* receives an additional supply from the deep external branches of the cervical plexus.

*Intercostal Muscles.*—These fill up the *intercostal spaces*, and consist of muscular and tendinous fibers, the combination of the two kinds of tissue giving both contractility and strength. There are two sets of these muscles, external and internal.

*External Intercostal Muscles.*—These fill the intercostal spaces from the tubercles of the ribs to the costal cartilages, from which point to the sternum there is no muscular tissue. They arise from the lower borders of the ribs, and are inserted into the upper borders of the ribs below them. The direction of their fibers is obliquely downward and forward.

*Nerve-supply.*—The intercostal nerves.

*Internal Intercostals.*—Those which are attached to the true ribs extend from the sternum to the angles of the ribs, where the muscular tissue ceases to exist and a membranous structure takes its place as far as the vertebræ. Those which are attached to the false ribs extend from their cartilages backward in a manner similar to that just described. The fibers of this group arise from the ridge on the inner surface of the ribs and from the costal cartilages, and are inserted into the upper borders of the ribs below. The direction is *obliquely downward and forward*, the external and internal intercostals, therefore, cross each other.

*Nerve-supply.*—The intercostal nerves.

*Levatores Costarum.*—These muscles arise from the extremities of the transverse processes of the vertebræ from the seventh cervical to the eleventh dorsal, and are inserted into the upper borders of the ribs between the tubercles and the angle.

*Nerve-supply.*—The intercostal nerves.

*Action.*—The first rib on each side is raised and held in a fixed position by the *scaleni* muscles; the external intercostals now contracting, all the ribs are raised. This elevation of the ribs is assisted by the contraction of that portion of the internal intercostals which is situated in the front of the thorax, and by that of the *levatores costarum*. These are, therefore, all muscles of ordinary inspiration.

All authorities are not agreed as to the action of the intercostals. Haller regarded both external and internal intercostals as muscles of inspiration; Keen considers the external intercostals

as being depressors of the ribs, hence muscles of expiration ; while the function of the internal set he considers to be that of elevating the ribs, and therefore regards them as muscles of inspiration.

The form of the diaphragm, when its muscular tissue is relaxed, is that of a dome with its convexity upward. When the muscular fibers contract they pull down the central tendon, and at the same time become themselves less convex and straighter. This movement constitutes the *descent* of the diaphragm, and results in increasing the capacity of the thorax ; therefore the diaphragm is a muscle of inspiration—indeed, it is the most important of all the inspiratory muscles.

The abdominal cavity contains the abdominal organs—liver, stomach, spleen, intestines, etc.—and in its descent the diaphragm depresses these structures, which under the pressure yield to a certain extent, the protrusion of the abdominal walls aiding by allowing this displacement to take place to a greater degree than it would were they rigid. There is, however, a limit to the amount that the central tendon can descend, and when this limit is reached the tendon becomes a fixed point from which the muscular tissue can act, and the effect is to raise the lower ribs to which it is attached ; thus the capacity of the thorax is still more increased. This descent amounts to from 5.5 mm. to 11.5 mm. in quiet breathing and 42 during forced inspiration. Not only are the abdominal organs depressed, but they are also compressed, and their attachments put upon the stretch ; when, therefore, the muscular tissue of the diaphragm ceases its contraction and begins to relax, the elasticity of the depressed and compressed abdominal contents and the abdominal walls tends to raise the diaphragm into the position it occupied at the beginning of the respiratory act. This ascent of the diaphragm is, therefore, a phenomenon of expiration.

**Muscles of Forced Inspiration.**—Trapezius, latissimus dorsi, rhomboideus minor, rhomboideus major, serratus posticus superior, serratus posticus inferior, iliocostalis, quadratus lumborum, sternomastoid, pectoralis major, pectoralis minor, subclavius.

*Trapezius.*—This muscle arises from the superior curved line of the occipital bone, the ligamentum nuchæ, spinous process of seventh cervical, and the spinous processes of all the dorsal vertebræ, and the supraspinous ligament, and is inserted into the clavicle, acromion process, and spine of the scapula.

*Nerve-supply.*—The muscular branch of the spinal accessory and branches from the anterior divisions of the third and fourth cervical nerves.

*Latissimus Dorsi.*—It arises from the spinous processes of the six lower dorsal and those of the lumbar and sacral vertebræ, the supraspinous ligament, crest of the ilium, and 3 or 4 lower ribs, and is inserted into the bicipital groove of the humerus.

*Nerve-supply.*—Middle or long subscapular nerve.

*Rhomboideus Minor.*—It arises from the ligamentum nuchæ and spinous processes of the seventh cervical and first dorsal vertebræ, and is inserted into the scapula at the root of the spine.

*Nerve-supply.*—The anterior division of the fifth cervical nerve.

*Rhomboideus Major.*—This arises from the spinous processes of the 4 or 5 upper dorsal vertebræ and the supraspinous ligament, and is inserted into the tendinous arch extending from the scapula at the root of its spine to its inferior angle.

*Nerve-supply.*—The anterior division of the fifth cervical nerve.

*Serratus Posticus Superior.*—This muscle arises from the ligamentum nuchæ and the spinous processes of the seventh cervical and 2 or 3 upper dorsal vertebræ and the supraspinous ligament, and is inserted into the second, third, fourth, and fifth ribs beyond their angles.

*Nerve-supply.*—The external branches of the posterior divisions of the upper dorsal nerve.

*Serratus Posticus Inferior.*—It arises from the spinous processes of the eleventh and twelfth dorsal and the 2 or 3 upper lumbar vertebræ and supraspinous ligament, and is inserted into the four lower ribs beyond their angles.

*Nerve-supply.*—The external branches of the posterior division of the lower dorsal nerves.

*Iliocostalis.*—This is sometimes called *sacro-lumbalis*. It is the outer part of the erector spinæ which arises from the sacro-iliac groove, and forms a broad tendon attached to the sacrum, lumbar vertebræ, supraspinous ligament, and that of the ilium and the sacrum. It is inserted into the angles of the 6 or 7 lower ribs.

*Nerve-supply* comes through the external branches of the posterior divisions of the lumbar and dorsal nerves.

*Quadratus Lumborum.*—It arises from the iliolumbar ligament and the crest of the ilium, and is inserted into the last rib and the transverse processes of the 4 upper lumbar vertebræ.

*Nerve-supply.*—The anterior branches of the lumbar nerves.

*Sternomastoid.*—It arises from the sternum and clavicle, and is inserted into the mastoid process of the temporal bone and the occipital bone.

*Nervous Supply.*—The spinal accessory and deep branches of the cervical plexus.

*Pectoralis Major.*—It arises from the clavicle, sternum, cartilage of the true ribs, aponeurosis of the obliquus externus, and is inserted into the anterior bicipital ridge of the humerus.

*Nervous Supply.*—The anterior thoracic nerve.

*Pectoralis Minor.*—It arises from the third, fourth, and fifth ribs, and from the aponeurosis covering the intercostal muscles, and is inserted into the coracoid process of the scapula.

*Nervous Supply.*—The anterior thoracic nerves.

*Subclavius.*—It arises from the first rib and its cartilage, and is inserted into the clavicle.

*Nervous Supply.*—A filament from the cord formed by the union of the fifth and sixth nerves.

*Serratus Magnus.*—It arises from the 8 upper ribs and the aponeurosis covering the intercostal muscles, and is inserted into the scapula.

*Nervous Supply.*—The posterior thoracic nerve.

*Action.*—The trapezius and rhomboidei fix the scapula, and the serratus magnus, contracting, raises the ribs. The arm being fixed, the latissimus dorsi also raises the ribs. The ribs are likewise elevated by the action of the serratus posticus superior, while the serratus posticus inferior draws downward and backward the lower ribs, increasing thereby the capacity of the thorax. Some authorities regard the serratus posticus superior as being brought into action in ordinary respiration. When the ribs are drawn downward they are held there by the serratus posticus inferior, thus overcoming the upward lifting of the ribs by the diaphragm. The iliocostalis and quadratus lumborum fix the last rib and oppose the tendency of the diaphragm to raise it. The head being fixed, the sternomastoid elevates the thorax. The group of muscles consisting of the pectoralis major and minor and the subclavius draw the ribs upward when the head is fixed.

In this manner all the muscles mentioned, some to a greater and some to a lesser degree, aid in the process of forced inspiration.

**Muscles of Forced Expiration.**—Internal intercostals, triangularis sterni, obliquus externus, obliquus internus, transversalis, rectus.

*Internal Intercostals* (p. 368).

*Triangularis Sterni.*—This muscle is situated on the back of the sternum and anterior portion of the ribs. It arises from the sternum, ensiform cartilage, and costal cartilages of the 3 or 4 lower true ribs, and is usually inserted into the costal cartilages of the second, third, fourth, and fifth ribs.

*Nerve-supply.*—The intercostal nerves.

*Obliquus Externus.*—This muscle is more familiarly known as the *external oblique*. It arises from the 8 lower ribs, and is inserted into the crest of the ilium and into tendinous fibers which form a broad aponeurosis.

*Nerve-supply.*—The lower intercostal nerves.

*Obliquus Internus.*—This is also called the *internal oblique*. It arises from Poupart's ligament, the crest of the ilium, and the posterior lamella of the lumbar fascia, and is inserted into the os pubis, linea alba, through an aponeurosis to the cartilages of the seventh, eighth, and ninth ribs, and into the cartilages of the tenth, eleventh, and twelfth ribs.

*Nerve-supply.*—The lower intercostal nerves and the ilio-inguinal nerve.

*Transversalis.*—It arises from Poupart's ligament, the crest of the ilium, cartilages of the 6 lower ribs, and transverse processes of the lumbar vertebræ, and is inserted into the linea alba or pubes.

*Nerve-supply.*—The lower intercostal nerves.

*Rectus Abdominis.*—It arises from the os pubis, and is inserted into the cartilages of the fifth, sixth, and seventh ribs.

*Nerve-supply.*—The lower intercostal nerves.

*Action.*—The internal intercostal muscles, except the anterior portion (p. 368), depress the ribs, at the same time inverting their lower borders, thus diminishing the size of the thoracic cavity.

The triangularis sterni draws down the costal cartilages, thus aiding in the expelling of air from the lungs.

When the pelvis and the spine are fixed, the external and internal oblique, transversalis, and the rectus compress the thorax at its lower part, and thus assist in the expiratory process.

### RESPIRATORY MOVEMENTS.

The respiratory movements are of two kinds—inspiratory and expiratory.

**Inspiratory Movements.**—By virtue of the inspiratory movements the air passes into the lungs. During their performance the thorax expands under the influence of the diaphragm and the inspiratory muscles (p. 367). In inspiration all the diameters of the chest are increased. The descent of the diaphragm increases the vertical diameter (Plate 1). At the same time the transverse and anteroposterior diameters are also increased. The shape and direction of the ribs are such that when they are raised their convexities are carried outward, and thus the transverse diameter of the thorax is increased. But this movement also carries the sternum forward, thereby increasing the anteroposterior diameter. Under some circumstances, as when there is some obstruction to the entrance of air, additional muscles, called *extraordinary muscles of inspiration* or *muscles of forced inspiration* (p. 369), are brought into action. In this way most of the muscles about the thorax may be called upon. It should be noted that inspiration is an active process—that is, one that requires for its performance the action of muscles.

**Expiratory movements** are for the most part passive in their nature—that is, are not due to muscular contraction. During the descent of the diaphragm, referred to in describing the inspiratory movements, the elastic abdominal organs and their attachments and the abdominal walls are put upon the stretch. At the end of the inspiratory act the diaphragm ceases to contract, and



by virtue of the elasticity of these structures the contents of the abdomen return to the position they occupied at the beginning of the diaphragm's descent, and in so doing this structure is carried back to its original position. The elevation of the ribs by the contraction of the external intercostals during inspiration twists the elastic costal cartilages which join the ribs to the sternum: as soon as these muscles cease to contract these cartilages untwist, and in so doing aid in the return of the ribs. In describing the structure of the lungs it was stated that the walls of the lobules are rich in elastic tissue: in inspiration these lobules are greatly distended, their walls being put on the stretch. When the inspiratory forces cease to act, then this tissue, by virtue of its elasticity, returns to its former condition, and in so doing expels the air, constituting expiration. Contractility may be said to be the inspiratory force; elasticity, the expiratory force.

As in inspiration, so in expiration, there are occasions when obstruction to the outgoing air exists, and forced expiration becomes necessary. The muscles concerned in this act are known



FIG. 210.—The larynx in gentle breathing: *L*, epiglottis; *V*, vocal cords; *S*, cartilages of Santorini, which surmount the arytenoid cartilages; *P, P*, ventricular bands (Lennox-Browne).

FIG. 211.—The larynx in deep breathing: *W, P*, tracheal rings; *B*, openings of bronchi; *P, P*, ventricular bands (Lennox-Browne).

as *extraordinary muscles of expiration* or *muscles of forced expiration*, whose arrangement is such that in their contraction the capacity of the thorax is diminished. They have been already described (p. 371). The abdominal walls, by exerting pressure on the abdominal viscera, and thus on the diaphragm, still further diminish the thoracic cavity and force out the contained air.

**Movements of the Glottis.**—There are in connection with the process of respiration certain movements of the glottis which are important. On examination of the interior of the larynx it will be seen that during inspiration the vocal cords separate, and during expiration approach each other. During deep breathing (Fig. 211) the separation of the cords is greater than in quiet breathing (Figs. 210, 219).

The area of the trachea is nearly three times that of the space between the cords at the beginning of inspiration. The separation of these cords is effected by the contraction of the posterior crico-arytenoid muscles, which, by their attachment to the arytenoid cartilages, rotate these outward, and thus separate the posterior



ends of the cords which are attached to them, increasing the area nearly twofold. When these muscles cease their contraction, as they do at the end of the inspiratory act, then the elasticity of the cartilages brings the muscles back to the position they occupied at the beginning of inspiration. These movements of the glottis occur synchronously with the respiratory movements of the thorax. The muscles of the larynx have already been described (p. 355).

### CAPACITY OF THE LUNGS.

At the beginning of an ordinary inspiration the lungs contain air, which so distends them that the visceral layer of the pleura is in contact with the parietal layer. As the thorax enlarges the air in the lungs distends them still more, so that they are still kept in contact with the thoracic walls. This contact between the visceral and parietal layers of the pleura is constant, irrespective of the amount of distention of the lungs. The expansion of the air in the lungs makes it of less density than the external air with which it is in communication through the air-passages, and immediately there is a flow of external air into these passages to establish an equilibrium: this inflow constitutes *inspiration*. Immediately following air is expelled from the lungs, and this outflow constitutes *expiration*. To this volume of air which flows in and out during *ordinary* respiration the name of *tidal air* is given, from the resemblance which the process bears to the flow and ebb of the tide. The amount of this tidal air is variously stated by different authorities; some place it as low as 49 c.c., and others as high as 1640 c.c. It varies greatly in different individuals, and in the same individual according to the manner and frequency of his breathing. Hutchinson has made 80 determinations on different individuals, and obtained from 114 c.c. to 196 c.c. in a condition of rest, and from 262 c.c. to 360 c.c. during exercise. One observation was as high as 1262 c.c. In newborn children it is 35 c.c.

Each individual has the power, however, of taking into the lungs an additional amount of air over and above the tidal air, by a deep or *forced inspiration*. To this additional amount the term *complemental air* is applied, and it may be regarded as averaging about 1500 c.c.

As more air is taken in by forced inspiration than is usually inhaled during an ordinary inspiration, so by a forced expiration more air is expelled than is ordinarily exhaled during an ordinary expiration. To the air thus expelled during a *forced expiration* the name of *reserve* or *supplemental air* is given. Hutchinson states the amount to vary from 1148 c.c. to 1804 c.c., while by some it has been placed at 2624 c.c.

But even after all the air has been expelled that can be by

bringing into play all the muscles and other forces available, there still remains a volume of air which cannot be forced out ; this is the *residual air*, and has been estimated by Sir Humphrey Davy to be 674 c.c. It has been measured by different observers upon both the living and the dead body. In one set of observations upon 9 corpses, the minimum was 640 c.c., the maximum, 1231 c.c., the mean, 981 c.c. In another series of observations on living males the results were 440 c.c. minimum, 1250 c.c. maximum, and 796 c.c. mean ; and in still another upon living females, 347 c.c. minimum, 526 maximum, and 478 c.c. mean. Neupauer determined the amount of residual air in a living subject to be very much greater.

**Vital capacity** is the volume of air over which an individual can exert control. It is the amount which he can expel by a forced expiration after having taken a forced inspiration ; it is, therefore, the sum of the tidal, complemental, and supplemental air ; it excludes the residual air. Hutchinson gives it as 3558 c.c., basing his estimate on 1923 observations.

The vital capacity of the newborn child is about 120 c.c.

Although it is impossible to give any figures which will represent measurements that are necessarily so variable as those just given, still it may be of use to have an approximate estimate for purposes of reference ; and we may place the amount of tidal air at 300 c.c., complemental air at 1500 c.c., reserve air at 1500 c.c., and residual air at 1000 c.c.

**Frequency of Respiration.**—In the newborn child the number of respirations per minute is 44 ; at five years of age, 26 ; at twenty years, 20 ; at thirty years, 16 ; and at fifty years, 18. These figures represent an average during a quiescent condition. Should the respirations be counted during sleep, they would be 1 or 2 less per minute ; during great activity they would be increased considerably, in the adult running up to 30 or more.

## TYPES OF RESPIRATION.

It has been the practice among writers on physiology to speak of the *superior costal* or *female* type of respiration and the *abdominal*, *inferior costal*, or *male* type. The following condensed statement from one of the best text-books on this subject represents the views of these writers : “ In children, as well as in the adult male, under ordinary conditions, the diaphragm performs most of the work, and the movements of the abdomen are the only ones especially noticeable . . . . In the female the movements of the chest, particularly of its upper half, are habitually more prominent than those of the abdomen, and this difference in the mechanism of respiration is characteristic of the sexes.” The protrusion of the abdominal wall, caused by the descent of the

diaphragm, is very marked in children, and produces the abdominal type of respiration. The costal type spoken of above as characteristic of the female was supposed to be a wise provision of nature, in order that when pregnancy should occur the respiratory movements would not be interfered with, as they would be did the female possess the inferior costal type of respiration seen in the male.

Very careful and complete studies of women in and out of civilization, the lower portions of whose chests have never been compressed with corsets or with other devices calculated to prevent expansion of these parts, have demonstrated that the supposed respiratory difference in male and female does not exist naturally, and that when it is found it is due to the corset, and not to any peculiarity of sex. Indeed, if the male chest is encased in a corset, the inferior costal type becomes changed at once into the superior costal. It is also of interest to note that in one case at least the observation was made in which the inferior costal type of respiration was well marked in a pregnant woman within one week of her confinement.

#### CHEMISTRY OF RESPIRATION.

The air, when dry and measured at 0° C. and 760 mm. pressure, contains 20.96 parts by volume of oxygen, 79.02 parts of nitrogen, and 0.03 part of carbon dioxid. About 1 per cent. of what is given as nitrogen is argon. Watery vapor is also present, the amount varying under different circumstances, being greater the higher the temperature of the air. The term *absolute humidity* has reference to the total amount of watery vapor which a volume of air contains, irrespective of the question of temperature; the term *relative humidity* is used to express the proportion of watery vapor present in the air at certain temperatures as compared with air fully saturated, saturation being expressed by 100. Absolute humidity is expressed in grams per cubic meter or in grains per cubic foot, while relative humidity is expressed in percentages. Thus if the temperature of the air is 4° C., and it is saturated with watery vapor, its relative humidity would be said to be 100; if, now, its temperature was raised to 27° C. its relative humidity would be only 24, because the higher the temperature the more vapor can a given volume of air contain, and the air at 27° C. would hold a much greater amount than when its temperature was 4° C.

The amount of moisture present in air is an important factor in the preservation of health. If it is too dry, the air-passages are irritated; while if too moist, there is produced a feeling of oppression. A relative humidity of 70 is, as a rule, very agreeable. Traces of ammonia, some ozone, and sodium chlorid are

also found in the atmospheric air. Besides these constituents, which are universal, there are many others that may or may not be present as the result of processes of manufacture.

**Expired Air.**—When the atmospheric air has been breathed its composition is markedly changed in the following particulars: 1. It has gained carbon dioxid, the amount being increased from 0.03 or 0.04 part per cent. to 4.38. 2. It has lost oxygen, the 20.96 volumes per cent. being reduced to 16.03, or about 5 per cent. It should be noted that the loss of oxygen is greater than can be accounted for by the amount of that gas returned in the carbon dioxid, the difference representing the amount used up in processes of oxidation constantly going on in the body. 3. It has gained watery vapor, the expired air being saturated. The actual amount of vapor which it receives while in the lungs will, of course, vary. If the air when inspired is cool and dry, it will absorb more moisture from the body than if it is moist and warm. The daily loss from this source is about 540 grams. 4. The expired air is, as a rule, warmer than the inspired. Thus in a series of observations it was found that when the inspired air had a temperature of from 15° to 20° C., when expired its temperature was 37.3° C.; when the inspired air was —6.3° C., it was 29.80° C. when expired; and when 41.9° C. at inspiration, it was 38.1° C. at expiration. The inspired air is warmed from 1 to 2 degrees more when taken in by the nose than by the mouth. 5. The actual volume of expired as compared with inspired air is less by about 2 per cent. 6. The expired air contains certain volatile organic matters, whose presence is at once recognized by the sense of smell, among them *crowd-poison*, although chemists have not yet made us acquainted with their exact composition.

The following table represents the average composition and temperature of inspired and expired air:

	Inspired Air.	Expired Air.
Oxygen . . . . .	20.96	16.03
Nitrogen . . . . .	78.00	78.00
Argon . . . . .	1.00	1.00
Carbon dioxid . . . . .	0.04	4.38
Watery vapor . . . . .	variable	saturated
Temperature . . . . .	"	about 37° C.

**Respiratory Quotient.**—This is a term employed to express the ratio between the carbon dioxid given off and the oxygen absorbed, and is obtained by dividing the former by the latter—*i. e.*,

$\frac{\text{CO}_2, 4.34}{\text{O}, 4.93} = 0.88$ , so that there is gained 0.88 volume of CO<sub>2</sub> for every volume of O absorbed. This ratio is an exceedingly variable one, differing in different animals, and even in the same individual with age, food, temperature of the air, during exercise, etc.

There are various reasons which account for these differences.

It is to be borne in mind, in the first place, that the sources of carbon dioxid in the animal body are numerous. The oxygen which is absorbed at any given time does not immediately appear in the carbon dioxid given off; it may be absorbed and enter into combinations, which may retain it for a considerable time; so that at any given time the amount of oxygen absorbed may be greater than that given off in the carbon dioxid, or *vice versa*.

Then, too, more  $\text{CO}_2$  is formed in proportion to the amount of oxygen absorbed by the decomposition of some substances than others. Thus when carbohydrates constitute the diet the amount of oxygen which they contain is enough to satisfy their hydrogen, but fats and proteids need more, and in the formation of water they use up oxygen; from this it follows that more oxygen is absorbed during an animal than during a vegetable diet. When the amount of carbon dioxid given off equals the amount of oxygen absorbed, the respiratory quotient is 1. The quotient will be higher in herbivora, where it is from 0.9 to 1.0, than in carnivora, where it is from 0.75 to 0.8. It is interesting to note that when an herbivorous animal is fasting—that is, at a time when it is taking in no food, but is living on its own tissues, and is therefore for the time being a carnivorous animal—the quotient is that of the carnivora, 0.75.

In observations upon man it is found that before feeding the quotient is 0.84 to 0.89; when meat or fat is given, 0.76; with potatoes, 0.93; and with glucose, 1.03.

The respiratory quotient is higher in adults than in children; during the day than at night; during wakefulness than during sleep; during activity than during rest.

**Ventilation.**—It is manifest that if at each inspiration oxygen is extracted from the air, in the course of time the amount of this gas will be so reduced as to make its want seriously felt. It is necessary, therefore, in order to keep the amount of oxygen up to the standard, that some provision should be made to supply it. Besides the removal of the oxygen, the air is still further rendered unsuited for respiratory purposes by the carbon dioxid, and especially by the organic matter thrown off by the expired air; the oxygen being still further diminished by stoves and lights, and the air being vitiated by the products of combustion. Another and no less important source of vitiation of the air is the organic matter thrown off from the skin, particularly in those of uncleanly habits. Decayed teeth and foul mouths add to the contamination. To supply oxygen and to remove these impurities are the objects of ventilation.

A common test to determine whether the air of an enclosed space contains sufficient oxygen for respiratory purposes is to see if a candle will burn in it. This test is used to determine whether the air in vaults or in excavations is fit for respiration. A candle will not burn if the air contains only 17 volumes per cent. of oxygen;

a man can breathe without difficulty if there are but 15 volumes per cent. So far, then, as the question of oxygen is concerned, a man could breathe where a candle would not burn, but it does not necessarily follow that it is always safe for a man to venture where a candle *will* burn, for sometimes, although there may be oxygen sufficient to sustain life, poisonous gases may also be present in an amount sufficient to produce a fatal result. It would be a surer test to place a dog in the suspected place and leave him there for twenty minutes. If it survives, it will be safe for a man to enter.

It is a matter of common experience that injury to health follows confinement in badly ventilated apartments, but the cause thereof has never been satisfactorily determined. The generally accepted theory is that it is not due to the carbon dioxid which is given off by the lungs, but to the organic matter—*crowd-poison*—exhaled in the expired air and also given off from the surface of the body, especially of those who are not cleanly in their habits, and who resort to bathing the body too infrequently. Those who maintain these views state that an air which contains respiratory  $\text{CO}_2$ —i. e.,  $\text{CO}_2$  produced by respiration—to the amount of more than 0.07 per cent. is unwholesome air to breathe, and yet that  $\text{CO}_2$  may be present to the extent of 2 per cent. provided that its presence is due to chemical processes, as in soda-water factories, and may be breathed without inconvenience or any injurious consequences resulting. Indeed, so reliable observers as Brown-Séquard and d'Arsonval have breathed air in which  $\text{CO}_2$  was present to the amount of 20 per cent. for two hours without marked distress. When, therefore, injurious effects follow from breathing air containing 0.8 per cent. of  $\text{CO}_2$ , which represents that present in a very badly ventilated lecture-hall, it must be due to something else than the  $\text{CO}_2$ , and they attribute it to the organic matter already referred to. Brown-Séquard and d'Arsonval, who believed that it was the organic matter from the lungs which was the poisonous matter, injected into rabbits the condensed vapor of the expired air with fatal results.

On the other side of the question are those who maintain that the injurious consequences of breathing vitiated air are due to the excessive amount of  $\text{CO}_2$  and the deficiency of oxygen, and not to organic matter. In support of this theory we have the following observations: Haldane and Lorraine Smith found that in breathing air containing 18.6 per cent. of  $\text{CO}_2$ , within a minute or two they suffered from hyperpnea, distress, flushing, cyanosis, and mental confusion; and the injections of condensed vapor-breath into rabbits, practised by Brown-Séquard and d'Arsonval, have been repeated by several experimenters with negative results. Besides these, other experiments have been performed, showing that no volatile poisons are exhaled with the expired air. Among recent investigations on this subject are those of Haldane and Lorraine Smith. From these they conclude as follows:



“1. The immediate dangers from breathing air highly vitiated by respiration arise entirely from the excess of carbon dioxid and deficiency of oxygen, and not from any special poison.

“2. The hyperpnea is due to excess of carbon dioxid, and is not appreciably affected by the corresponding deficiency of oxygen. The hyperpnea begins to appear when the carbon dioxid rises to from 3 to 4 per cent. At about 10 per cent. there is extreme distress.

“3. Excess of carbon dioxid is likewise the cause, or at least one cause, of the frontal headache produced by highly vitiated air.

“4. Hyperpnea from defect of oxygen begins to be appreciable when the oxygen in the air breathed has fallen to a point which seems to differ in different individuals: In one case the hyperpnea became appreciable at about 12 per cent., and excessive at about 6 per cent.”

Haldane and Smith also regard the odorous substances present in rooms due to a want of cleanliness as contributing to the discomfort caused by breathing the air of such rooms.

It must be remembered that the oxygen of the air is consumed and carbon dioxid and other impurities produced by stoves, gas-burners, and lamps, as well as by respiration. Thus a large gas-burner will in one hour consume as much oxygen as a human being will in five hours, and at the same time will be produced carbon dioxid and monoxid, sulphur compounds, and other gaseous impurities, all of which vitiate the air to a considerable degree. At the same time the air is heated. Perhaps one of the most important advantages which has accrued from the introduction of electricity as applied to illuminating-purposes is the entire absence of heat and of those impurities which so impoverish the air of inhabited rooms.

It is generally conceded that if the respiratory  $\text{CO}_2$  in the air does not exceed 0.02 per cent. above that which is ordinarily present in all air—0.03 or 0.04 per cent.—bringing it up to 0.06 or 0.07 per cent., no harm will result, and adequate ventilation will be secured—*i. e.*, keeping the  $\text{CO}_2$  from increasing beyond 0.06 or 0.07 per cent. To bring this about will require as a minimum 60,000 liters (2000 cubic feet) per hour per individual, but this should be increased by at least one-half (making it 3000 cubic feet) to provide for the increased production of  $\text{CO}_2$  caused by active exercise; and in factories and workshops where all the operatives are men, and all actively at work, this amount often needs to be as much as 6000 cubic feet. For hospitals, where the emanations from the sick are more likely to vitiate the air than are those from the well, at least 6000 cubic feet should be provided. These figures take no account of gas-burners or lamps, and for these there should be allowed not less than 1800 cubic

feet of air for each cubic foot of gas consumed, and 18,000 cubic feet for each pound of oil burned.

The *cubic space* allotted to each individual must also be taken into account, for experience has proved that unless the ventilating arrangements are very perfect, the air of an inhabited room cannot be changed oftener than three times an hour without causing draughts, which are uncomfortable, and it may be dangerous to health. It becomes necessary, therefore, to provide at least 1000 cubic feet of *air-space* per individual. In the dormitories of workhouses the amount allowed does not often exceed 300 cubic feet; in military barracks, 600 cubic feet, and in hospitals, 1200 cubic feet.

It has also been found by practical experience that in rooms that have a height of more than 12 feet the conditions are not favorable for proper ventilation, for the reason that organic matters have a tendency to remain in the lower parts of rooms. A room 50 feet high, with 20 square feet of floor-space, would give 1000 cubic feet of air-space, but it would not be the same from a sanitary point of view as a room 10 feet in all its dimensions. Attention must, therefore, be paid to the amount of *floor-space* allotted to each individual; this varies according to circumstances. It should be at least 100 square feet. Of course, where rooms are occupied for but a short time, as in theaters, churches, etc., where after the audiences are dismissed the buildings can be thoroughly aired by the admission of external air, all these restrictions do not apply.

It seems hardly necessary to say that due attention must be paid to the source from which the introduced air is drawn. If it is obtained from filthy cellars or from dirty streets, it may be as impure as that which it is designed to replace.

For any further discussion of this subject our readers are referred to text-books on hygiene.

**Changes in the Blood due to Respiration.**—When the blood reaches the lungs from the heart it is venous, and when it leaves the lungs to return to the heart it is arterial. The conversion, then, of the venous blood into arterial takes place while it is traversing the pulmonary capillaries. In its passage the bluish-red color which characterizes venous blood becomes changed to the scarlet color of arterial blood, and at the same time the venous blood gives up a portion of its  $\text{CO}_2$  to the air, and takes O from it. From 100 volumes of blood, whether arterial or venous, approximately 60 volumes of both gases can be obtained; the proportion, however, varying. Thus in human *arterial* blood there is O, 21.6;  $\text{CO}_2$ , 40.3; and N, 16. The amount of nitrogen is practically the same in both varieties of blood. It is impossible to give figures which represent accurately the composition of venous blood, for while analyses of arterial



blood taken from the different arteries vary but little, those of venous blood from different parts of the venous system vary to a considerable degree; and even the blood from the same vein will have a different composition at different times, as, for instance, that coming from a gland when active or at rest. In general, venous blood may be said to contain O from 8 to 12 per cent., and CO<sub>2</sub> about 46 per cent. Zuntz has made many analyses, and concludes, as a result, that venous blood, as compared with arterial, contains 7.15 volumes per cent. less of O, and 8.2 volumes per cent. of CO<sub>2</sub>.

Although arterial blood contains but 21.6 per cent. of O, still it can be made to take up as much as 23 per cent., which would about saturate it. But even the 21.6 per cent. is more than is needed by the tissues in their metabolic processes. Unless, therefore, the blood contains less oxygen than normal, there is no advantage to be derived from inhaling oxygen gas. If, however, the venous condition is marked, then oxygen inhaled under pressure may do good. While the arterial blood is nearly saturated with oxygen, experiments have shown that it can take up nearly four times as much CO<sub>2</sub> as it ordinarily contains.

**Causes of the Interchange between O and CO<sub>2</sub> in the Lungs.**—The trachea and bronchi can contain about 140 c.c. of air, so that at each inspiration, when 300 c.c. or more of tidal air are taken in, the difference between these two figures, 160 c.c. or more, must represent the amount which passes at each inspiration into the alveoli of the lungs. When expiration occurs an equal volume is exhaled; thus by the repeated alternation of inspiration and expiration the air in the lungs is being constantly changed.

But the most potent factor in bringing about this interchange is the *diffusion* of the gases, which depends upon their *partial pressure*—*i. e.*, the part of the total pressure of the air which is exerted by each of its different components. This is also spoken of as *tension* by some writers; although others use the term *partial pressure* with reference to gases in a mechanical mixture, as in atmospheric air; and that of *tension* with reference to gases in solution, meaning thereby “the pressure required to keep the gas in solution.” If we regard 760 mm. of mercury as representing the pressure of the atmosphere, and 20.96 as the percentage of the total volume

represented by oxygen, then  $\frac{20.96 \times 760}{100}$  will equal the pressure exerted by the oxygen, or its partial pressure or tension, which is 159.29 mm. The partial pressure of the CO<sub>2</sub> =  $\frac{0.04 \times 750}{100}$  =

0.30 mm. If now we ascertain the partial pressure of these gases in the alveoli, we shall have the principal conditions affecting their diffusion. The partial pressure of O in the alveoli is estimated at about 114 mm. and of CO<sub>2</sub> at 36 mm. The O then in the air

as it enters the respiratory passages has a partial pressure of 159.29 mm., while in the alveoli it is only 122 mm. ; therefore it will diffuse inward until it reaches the point of lowest pressure. On the other hand, the partial pressure of  $\text{CO}_2$  is greatest in the alveoli—38 mm. as compared with 0.30 mm. ; this gas will therefore diffuse outward.

There is a third force causing diffusion which is regarded as possessing different value by different authorities ; this is the *cardiopneumatic* movements. Each time the heart contracts it becomes smaller, and the pressure within the thorax, but outside the lungs—the *intrathoracic pressure*—is diminished, with the result of causing the lungs to expand slightly, and air consequently to enter them. When diastole occurs and the volume of the heart becomes larger, the intrathoracic pressure is relatively increased, and the air is forced out of the lungs. Besides, therefore, the entrance and exit of air due to the inspiratory and expiratory movements, there is a corresponding movement of the air due to the contraction and dilatation of the ventricles.

**Causes of the Interchange of O and  $\text{CO}_2$  between the Air and the Blood.**—The fact that the amount of O and  $\text{CO}_2$  in the blood does not follow the general law that the amount of gas which a liquid absorbs depends to a great extent upon its pressure, is conclusive proof that these gases are not to any great extent in solution in the blood. O is in solution in the plasma, but to the extent of less than one volume, and in venous blood only about 5 per cent. of the  $\text{CO}_2$  present is in solution. Inasmuch as the amount of both of these gases is greatly in excess of these figures, we must look for some other explanation of their presence in the blood in the quantities in which they there exist than to solution.

When the gases are extracted from the blood, as they may be by the use of a pump devised for this purpose (Fig. 212), the oxygen which is in solution is given off gradually as the pressure is reduced, but it is not until the pressure has been reduced to from one-thirtieth to one-tenth of an atmosphere that most of it comes off, and this it does suddenly when this low pressure is reached. From this it is evident that most of the oxygen is in chemical combination, and this pressure at which the gas is given off is the *tension of dissociation*. From various observations and experiments we know that the combination is one between oxygen and hemoglobin, forming oxyhemoglobin. It has been ascertained that theoretically oxyhemoglobin can contain 23.38 volumes per cent. of O, although it never does, but only about 20 per cent., because the hemoglobin is not saturated ; still, blood from which the red corpuscles and consequently the hemoglobin have been removed, as in plasma or serum, can take up only 0.26 volume per cent. The tension of O in arterial blood is 29.64 mm. of mercury, and in venous blood 22.04 mm.

The *tension of  $\text{CO}_2$*  in the blood is as follows: In arterial blood 21.28 mm., and in venous blood 41.04 mm.  $\text{CO}_2$  exists in venous blood in solution to the amount of about 5 per cent.; in loose chemical combination, 75 to 85 per cent.; and in firm chemical combination, 10 to 20 per cent.—or about 45 volume per cent. in all. The  $\text{CO}_2$  is in solution in the plasma, in combination with globulin and alkali, and with sodium in the form of carbonates and bicarbonates. About one-third of the carbon dioxide of the

FIG. 212.—Kemp's gas pump. (For detailed description see *American Text-Book of Physiology*, vol. i., p. 420.)

blood exists in the blood-corpuscles, both white and red, but principally in the latter, where it is in combination with the alkaline phosphates, with globulin and hemoglobin.

We have seen that by various forces the oxygen in the outside air reaches the alveoli, while in turn the carbon dioxide in the latter situation reaches the exterior; we have now to consider how the interchange between the  $\text{CO}_2$  in the blood and the O in the alveoli is effected. We have learned that the tension of the O

in the alveolar air is about 114 mm., although one observer at least places it as low as 99 mm. This has never been accurately determined. The tension of  $\text{CO}_2$  in the alveolar air is about 36 mm. In order to ascertain why the O of the air goes to the blood and the  $\text{CO}_2$  of the blood to the air, we must first know the tension of O and  $\text{CO}_2$  in the blood. For this purpose an instrument known as an *aërotonometer* is used. The principle underlying this instrument is thus described by Pembrey in Schäfer's *Physiology*: "Blood in contact with a mixture of oxygen, nitrogen, and carbon dioxid gives up some of its gases if their partial pressures are greater than those of the corresponding gases in the mixture; on the other hand, if the tensions of the gases in the blood be lower than the respective tensions of the gases in the mixture, the blood takes up gas. These interchanges persist until equilibrium is established, until the tension or partial pressure of the gas in the blood is equal to that of the corresponding gas in the mixture. In the aërotonometer the blood is made to pass in a thin layer through a glass tube or tubes containing mixtures of gases of known quantity and tension, and it is arranged by practice that the tension of the gases shall in the one case be greater, in the other case smaller, than the tensions of the corresponding gases in the blood. The gases in these tubes, after the blood has passed through them, are analyzed, and from the alteration in the proportion in the two tubes it is possible to calculate the partial pressure of the gases in the blood. The aërotonometer is surrounded by a water-jacket with a temperature of  $39^\circ \text{C}$ ."

Another aërotonometer is that of Fredericq, and Bohr has devised one known as an *hemato-aërometer*.

The results obtained by these different instruments vary considerably. Strassburg gives the tension of  $\text{CO}_2$  in venous blood of the right side of a dog's heart as 5.4 per cent. of an atmosphere; and 2.2 to 3.8 per cent. in arterial blood. Herter gives the tension of O in arterial blood as 10 per cent. of an atmosphere. Bohr has obtained quite different results: 101 to 104 mm. of mercury for the tension of O in arterial blood—higher than that of the air in the trachea. He also found that when the dog, the subject of the experiment, breathed pure air, the tension of the  $\text{CO}_2$  in arterial blood rises from nothing to 28 mm. of mercury, and when the dog breathed air containing  $\text{CO}_2$  the tension varied between 0.9 and 57.8 mm. That is to say, the tension of  $\text{CO}_2$  was greater in the tracheal air than in the blood. If this is so, it is manifest that the passage of the  $\text{CO}_2$  of the blood outward to the air could not be due to diffusion; so that to explain the actual facts Bohr concludes that the tissues of the lungs play an active part in the absorption of oxygen and the elimination of carbon dioxid. Haldane and Lorraine Smith have substituted for the aërotonometer a method by which "the tension of O in the

arterial blood is calculated from the percentage of carbon monoxid breathed by the subject of the experiment, and from the final saturation of his blood with carbon monoxid" (Pembrey). Their results are 26.2 per cent. of an atmosphere, or 200 mm. of mercury, about twice that of oxygen in the alveoli, which would confirm Bohr's views that diffusion cannot account for the absorption of oxygen by the blood while flowing through the pulmonary capillaries, but that it is to be attributed to the epithelial cells of the alveoli.

Notwithstanding these results, which need further investigation, diffusion is usually regarded as the principal factor in determining the gaseous interchanges between the air and the blood.

**Causes of the Interchange of O and CO<sub>2</sub> between the Blood and the Tissues.**—This process constitutes *internal respiration*.

Oxygen when it reaches the tissues by the blood is immediately taken up by them and enters into chemical combination, so that as oxygen it may be said not to exist, except momentarily. On the other hand, the tension of oxygen in arterial blood is relatively high, so that its passage from the blood to the tissues is readily accounted for. The tension of CO<sub>2</sub> in the tissues is about 58 mm. of mercury higher than in the blood; hence its passage outward from the tissues to the blood.

**Innervation of the Respiratory Apparatus.**—The nervous supply to the respiratory apparatus comes from the *respiratory center*, a collection of nerve-cells in the lower part of the medulla oblongata, though its exact location is not yet determined. Other centers, *subsidiary centers*, have been described, but their independence of the principal center is questioned.

The respiratory center is in reality made up of two centers, one for each side, so that, although anatomically connected and ordinarily acting together, yet if one center is broken up, while the respiratory movements on that side cease, those on the other side continue.

Besides this double character of the center, each half is made up of an *inspiratory* and an *expiratory* center—*i. e.*, the nervous impulses which originate and pass out from the inspiratory center produce inspiratory movements, and those from the expiratory center bring about movements of expiration.

The respiratory center is both an *automatic* and a *reflex* center—*i. e.*, it sends out *spontaneously* impulses which result in movements of the respiratory muscles, constituting its *automatism*; and it may also be excited *reflexly*—*i. e.*, by impulses reaching it from without. Its reflex character is most marked, and it is doubtless as a reflex center that its function is ordinarily performed.

**Rhythm of the Respiratory Movements.**—One of the striking characteristics of the respiratory movements is their

*rhythmicality*—*i. e.*, the regularity with which expiration follows inspiration, then a pause, and again an inspiration followed by an expiration. It is true that this regularity is not as marked in the aged and in children as in others, but in a condition of health it is not markedly departed from. In certain forms of disease, however, the respiratory movements are very irregular. One such is *Cheyne-Stokes* respiration (Fig. 213), which may occur in fatty degeneration of the heart, uremia, some brain diseases, etc. It is

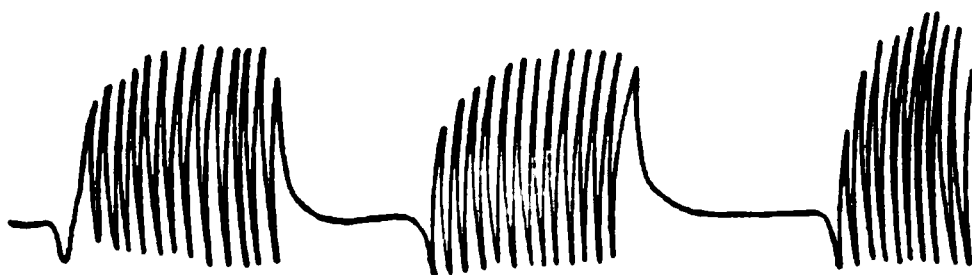


FIG. 213.—Cheyne-Stokes respiration (after Waller).

characterized by a beginning shallowness of respiration, the respirations gradually becoming deeper and deeper, then a return to shallowness, and finally a complete cessation of respiratory movements. This pause lasts for half a minute or more, when the shallow movements begin as before, followed by deeper and again by shallower respirations and then by a pause, etc. This grouping of the respirations is shown in the above curve of this kind of breathing.

In all reflex acts not only must there be nerve-centers which receive the impulses coming from without and those which generate and emit impulses, but there must be *afferent* nerves to carry the impulses to the centers and *efferent* nerves to carry the outgoing impulses. The main afferent respiratory nerve is the *vagus* or *pneumogastric*, and it has been demonstrated that this nerve contains two kinds of nerve-fibers—one which carries the impulses to the inspiratory and the other to the expiratory center, so that division of one nerve slows and deepens respiration to some degree, much more when both nerves are divided. If the end still in communication with the nerve-centers, the *central* end, is stimulated powerfully with electricity, the movements of inspiration become greater, and the diaphragm not only contracts—*i. e.*, descends—but remains in the position of contraction. If, on the other hand, only a weak stimulus is applied, the expiratory movements are increased, and the diaphragm remains in the position it is in at the end of expiration. It has further been demonstrated that whenever air is pumped into the lungs so as to distend them, the contraction of the diaphragm diminishes, and when fully distended the diaphragm is in the expiratory position—*i. e.*, as it is at the end of an expiration. This distention of the lungs constitutes *positive ventilation*. On the other hand, if air is pumped out of



the lungs, the alveoli collapse, and the contractions of the diaphragm increase, and finally the diaphragm becomes quiescent in the inspiratory position. Analogous conditions occur in normal breathing. When the lungs are distended, as in inspiration, the expiratory fibers of the vagus are stimulated, and an expiratory act follows; when expiration is complete and the alveoli are in the condition of diminished size, it can hardly be called collapse; the inspiratory fibers are stimulated and an act of inspiration occurs.

Other afferent respiratory nerves are the superior laryngeal, glossopharyngeal, trigeminus, and sensory nerves of the skin.

The *superior laryngeal* is the sensory nerve of the larynx, and whenever any foreign body touches this sensitive organ, or when food is inclined to go down the "wrong way"—i. e., gets into the larynx instead of the esophagus—inspiration is at once stopped and violent coughing ejects it. In this process the afferent impulses are carried to the respiratory center, and not only is the inspiratory center restrained or *inhibited*, but the expiratory center is stimulated, and a pronounced expiratory effort, the cough, results.

The *glossopharyngeal* is also an afferent respiratory nerve, and carries to the inspiratory center inhibitory impulses that cause all inspiratory movements to cease, as when food is swallowed. The food stimulates the terminations of the nerve in the mucous membrane of the pharynx, and the inhibition results. Were this not so, there would be danger of food entering the larynx at the time of inspiration.

The *trigeminus* sends fibers to the mucous membrane of the nose, and when these fibers are irritated by an irritant like ammonia, respiration may be arrested.

The *nerves of the skin* also act as afferent respiratory nerves, as is well shown when cold water is dashed on the body.

The *efferent respiratory* nerves are the *phrenics*, which supply the diaphragm; the *vagi*, which supply the muscles concerned in producing the respiratory movements of the glottis (p. 373); and the *spinal* nerves, which supply the respiratory muscles of the thorax.

There are certain terms used in connection with respiration which need to be understood.

*Eupnea*.—This term means easy respiration, and is applied to the normal act.

*Apnea*.—This term as used by physiologists, *physiologic apnea*, applies to a condition in which the respiratory movements are suspended, as when the lungs are distended with air forced in by a pair of bellows. It was formerly attributed to the hyperoxygenation of the blood, but this cannot be the only explanation, because if hydrogen is the distending gas, apnea results. Distention with air is practically what has been described as *positive*

*ventilation.* It appears, however, from experiments that when the lungs have been distended with air, there is besides the distention enough oxygen in the alveoli to aërate the blood for a time, so that it is probable that physiologic apnea is produced by positive ventilation, distention, and the excess of oxygen in the alveoli. Apnea is also used as a synonym for asphyxia; in this case the qualifying adjective "physiologic" is omitted.

*Dyspnea.*—This is difficult or labored breathing. If caused by a deficiency of oxygen, it is *O-dyspnea*; if by an excess of carbon dioxid, *CO<sub>2</sub>-dyspnea*.

*Hyperpnea.*—In this form of breathing the rate is moderately accelerated.

*Asphyxia.*—The term literally means *pulselessness*, and is especially applicable to the last stage.

If by any means the supply of air to an animal is cut off, or so diminished in amount as to be exhausted, the animal dies in a short time from asphyxia, passing previous to the fatal termination through the following stages:

(1) *Hyperpnea.*—This stage is characterized by an increased frequency of the respiratory movements, especially marked during inspiration, because of the increased stimulation of the inspiratory center.

(2) *Dyspnea.*—In this stage, the expiratory center is especially stimulated, and as a result the movements of expiration are more pronounced than those of inspiration, the expiratory muscles (p. 371) being brought into action. These two stages last about one minute.

(3) *Convulsion.*—This stage is characterized by convulsive movements throughout the body.

(4) *Exhaustion.*—The expiratory muscles being exhausted, the animal becomes quiescent, only a few slight attempts at inspiration being perceptible. After a time these become deeper, but only occur at comparatively long intervals.

(5) *Inspiratory Spasm.*—The intervals between the inspirations have in this stage greatly increased, and apparently ceased, but they recur occasionally. The pupils are dilated and the pulse becomes less and less perceptible; finally a last inspiration occurs and the animal is dead.

## VOICE AND SPEECH.

The voice is produced by the vibration of the true vocal cords, vocal bands, or vocal ligaments, by all of which terms they are called, these being set in vibration by the respired air as it passes out from the lungs, if at the time the bands are approximated and tense, and if, also, the current of air is sufficiently strong. At the same time, the sounds produced by the vibrating bands are sup-



plemented by the cavities above and below them, which act as resonators. For the anatomy of the larynx the reader is referred to page 354; in order to understand voice-production a knowledge of the anatomy of this organ is absolutely essential. Especial attention should be paid to the muscles and their action.

**Laryngoscope.**—In order to observe the changes which take place in the vocal bands, use is made of the laryngoscope. This instrument also enables the physician to study the other structures of the larynx and trachea, and to treat any diseases of these organs which may be present.

The laryngoscope consists of a concave head-mirror with an aperture in its center, and one or more small hand-mirrors. The

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FIG. 214.—The laryngoscopic image in easy breathing: 1, base of the tongue; 2, median glosso-epiglottic ligament; 3, vallecule; 4, lateral glosso-epiglottic ligament; 5, epiglottis; 6, cushion of epiglottis; 7, cornu major of hyoid bone; 8, ventricular band, or false vocal cord; 9, true vocal cord; opening of the ventricle of Morgagni seen between 8 and 9; 10, folds of mucous membrane; 11, sinus pyriformis; 12, cartilage of Wrisberg; 13, aryteno-epiglottic fold; 14, rima glottidis; 15, arytenoid cartilage; 16, cartilage of Santorini; 17, posterior wall of pharynx (Stoerk).

person whose larynx is to be inspected is seated at the side of a lamp, gas, or electric light, and in front of him is seated the observer, with the head-mirror so attached that he can look through the aperture in its center. The observed now opens his mouth, the head being thrown back, and with a napkin the tongue is drawn out and its tip is held against the lower teeth, by which act the epiglottis is drawn forward. One of the hand-mirrors is then slightly heated and passed into the mouth, its back elevating the uvula; the head-mirror is then so directed as to reflect the light on the hand-mirror and illuminate the image formed by it of the larynx and trachea. If the hand-mirror is not heated, the vapor of the expired air will be condensed upon it, obscuring the reflected image. To avoid overheating it and burning the

parts of the throat with which it comes in contact, the observer touches it to the back of his hand before introducing it.

The image which is seen (Fig. 214) is reversed—*i. e.*, the epiglottis appears in the upper portion of the image, and the left side of the larynx is at the right, as seen by the observer.

**Laryngoscopic Image during Respiration.**—If the glottis is examined in the cadaver, the separation of the bands is but about 1 or 2 mm., while during life, when ordinary or *quiet breathing* is taking place, the separation amounts to 3 to 4 mm. Nor is there, in most individuals, much difference between ordinary inspiration and expiration as to the width of the opening, although in some the bands do separate a little during inspiration and again approach during expiration. During deep inspiration the width of the rima glottidis may be 1.3 cm.

**Laryngoscopic Image during Voice-production or Phonation.**—When a tone is produced the vocal bands approach each other and are rendered more tense; and the greater the tension the higher is the note. Although in the production of a high note the cords are correspondingly approximated, still this does not seem to be essential, while increased tension of the cords is absolutely necessary to the production of a more elevated tone. It is claimed that the depression of the epiglottis and its consequent partial covering of the glottis render the tones produced by the vibrating bands lower in pitch, and that the epiglottis also acts as a sounding-board by reinforcing the vibrations of the air-column which impinges against it.

**Resonance.**—This is defined as “A prolongation or reinforcement of sound by means of sympathetic vibration, or the capability of producing such a continued sound” (*Standard Dictionary*): or “The property of a sonorous body that enables it to absorb the vibrations of another sonorous body and vibrate in unison with it” (Wentworth and Hill).

Bodies which possess this property are *resonators*, and good examples are *resonant boxes*, such as the body of a violin, which contain masses of air. The action of a resonator is illustrated

and explained as follows (Fig. 215): If a vibrating tuning-fork is held over the mouth of a cylindrical jar, of about 2 inches diameter and 12 inches deep, and water is poured in slowly, it will be noticed that as the air-column grows shorter, the sound grows

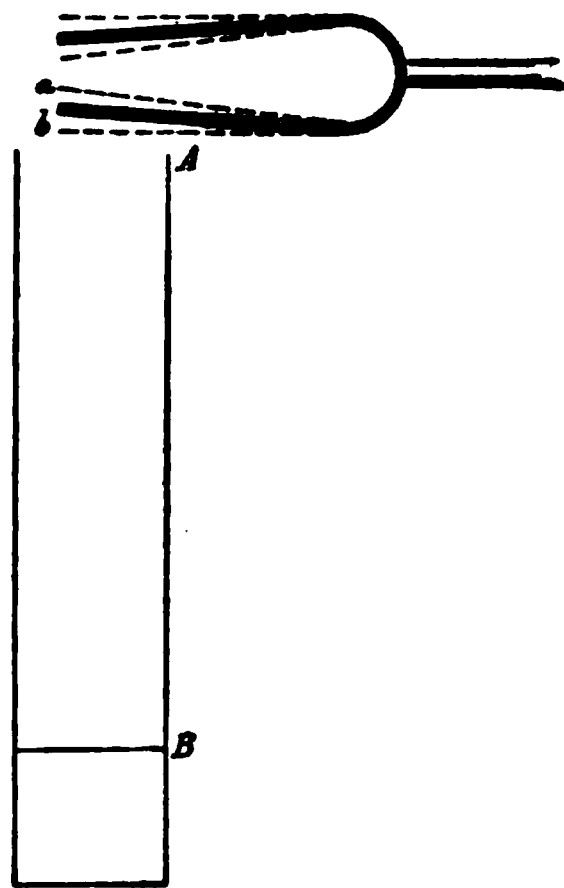


FIG. 215.—Tuning-fork and cylindrical jar, to illustrate resonance (Carhart and Chute).

louder until a certain length is reached, after which it grows weaker. Forks of different length will be found to have their own length of air-column, respectively, which reinforces its sound. The explanation is this: "When the prong *a* moves to *b*, it makes half a vibration, and hence generates half a sound-wave. The condensation it produces passes down the tube *AB*, is reflected from the bottom, and returns to unite with other waves sent out by the prong. Now, if *AB* is of the proper length, this condensation can move up the tube and return to combine with the condensation produced by the prong moving from *b* to *a*, thus making the condensation more marked and thereby strengthening the sound. The effect of the fork on the column of air is to set it in vibration, and the layer of air at its mouth has the sound-producing properties of a sonorous body of large area" (Carhart and Chute).

As already stated, the voice is produced by the vibrations of the tense vocal cords due to the expiratory blast of air emitted from the lungs. As in musical sounds, so in the voice, the three properties of intensity, pitch, and quality are to be found.

**Intensity.**—The *intensity* or *loudness* of the voice depends upon the amplitude of the vibrations of the bands, the force with which the air is emitted, and the resonance cavities, viz., the chest and the cavities of the head, all of which contain air. The air being set in sympathetic vibration by the vibrations of the vocal bands, reinforces the sound produced by the bands.

**Pitch.**—The pitch of the tones produced by the vibrating vocal bands depends upon the same elements as in any vibrating string—*i. e.*, length, tension, and thickness. Thus, the female voice is of a higher pitch than the male, because of the lesser length of the bands in the female than in the male.

The following table (Browne and Behnke) shows the vibrational number of a few extreme tones used in music:

Large organs . . . . .	C iv. . .	16½	vibrations per second.
Latest grand pianos . . . . .	A iv. . .	27½	" " "
Ordinary modern pianos . . . . .	C iii. . .	33	" " "
Double bass . . . . .	E iii. . .	41½	" " "
Pianos with usual compass . . . . .	A iii. . .	3520	" " "
" " exceptional compass . . . . .	C iv. . .	4224	" " "
Piccolo-flute . . . . .	D iv. . .	4752	" " "

The length of the bands in childhood is from 6 to 8 mm.; in the female adult about 11 mm., and may be stretched to 15 mm. or more; and in the male adult 15 mm., with a capability of extension to 20 mm. When the cricothyroid muscle contracts, the bands are lengthened and made tense. The structures of the bands and their attachments are such that they may vibrate as a whole or only in part; thus, when the vocal processes of the arytenoids are approximated, as they are by the contraction of the lateral crico-

arytenoid and transverse arytenoid muscles, the posterior portion of the bands does not vibrate, and the anterior portion alone vibrating produces a high note. The range of an individual voice is about  $2\frac{1}{2}$  octaves, while  $3\frac{1}{2}$  octaves is very exceptional. The range of the human voice is about  $5\frac{1}{2}$  octaves; the lowest bass, F iii., with 44 vibrations per second, and the highest note ever sung, so far as is recorded, B ii., corresponding to 1980 vibrations per second. This note was sung by the famous "Bastardella."

**Quality.**—Helmholtz defines the quality of a tone as "that peculiarity which distinguishes the musical tone of a violin from that of a flute, or that of a clarinet, or that of the human voice, when all these instruments produce the same note at the same pitch." The quality or *timbre* of the human voice is due to the fundamental and overtones produced by the bands, reinforced by those of the cavities of the head and chest acting as resonance-chambers.

**Registers.**—The term *register*, as applied to the voice, has two significations: (1) The range or compass of the voice; and (2) "a class or series of tones of a particular quality or belonging to a particular portion of the compass of a voice." Behnke defines a register as consisting of "a series of tones which are produced by the same mechanism." In singing up the scale, it will be noticed that at certain points there is a change or "break" in the quality of the voice, and at these points the voice is said to pass from one register to another. Thus, low notes belong to the *chest register*, and when they are emitted the chest will be felt to vibrate if one places one's hand upon it, and the voice produced is the *chest voice*: above this is the *middle register*, and the highest of all is the *head register*, in which the air in the head cavities acts as a resonator. Some prominent authorities denominate the middle register also *falsetto*, although this term is more commonly used with reference to certain peculiar high-pitched notes not often emitted, and said to be due to vibrations of the extreme edges of the cords only. The falsetto may be considered as a fourth register. Prof. Thos. R. French is of the opinion that "the female voice has three registers; and that it is quite probable that in voices with exceptional ranges there are four registers, but sufficient evidence has not yet been obtained to make this demonstrable."

**Speech.**—Phonation, or voice-production, is a faculty common to all animals having vocal bands, while the faculty of speech is peculiar to man. Channing says: "A man was not made to shut up his mind in itself, but to give it voice and to exchange it for other minds. Speech is one of our grand distinctions from the brute." It is possible that this attribute of man may not be solely his, as some recent observations on monkeys have been

made which would lead to the conclusion that they can communicate to a certain extent with their fellows.

**Vowels.**—These are sounds produced by vibrations of the vocal bands, but modified by the resonating cavities, to which modification the difference in their quality is due: and if the variations in the cavity of the mouth together with those of the tongue and soft palate are observed while different vowels are sounded, this fact will be readily understood (Fig. 216).

**Consonants.**—These are not produced by the vocal bands as are the vowels, but by obstructions placed in the way of an outgoing blast of air; and places where these obstructions are placed are *positions of articulation*. "The consonants are classified according to (1) their places of closure; (2) the completeness of the closure; (3) their utterance with breath or voice. The first distributes them into (a) *labials*, or lip-consonants—p, f, b, v, m, w; (b) *dentals*, or tooth-consonants—t, d, th, dh; (c) *palatals*, or palate-

FIG. 216.—Section of the parts concerned in phonation, and the changes in their relations in sounding the vowels A (<sup>ah</sup>), I (<sup>ee</sup>), U (<sup>oo</sup>): T, tongue; p, soft palate; e, epiglottis; g, glottis; h, hyoid bone; 1, thyroid; 2, 3, cricoid; 4, arytenoid cartilage (after Landois and Stirling).

consonants, including *sibilants*—s, z, sh, zh, and *liquids*, l, v, n, y; (d) *gutturals*, or throat-consonants—c-k, ch (Scottish lock), g, gh, (Irish lough), h, ng.

"The second division gives *mutes*, having tight closure—p, b, t, d, c-k, g; the other consonants are continuous.

"The third division gives: (1) *Surds*—p, t, ch, c (k), f, th (as in thin), s, sh, h. (2) *Sonants*—b, d, j, g, v, dh, z, zh, w, l, r, y, m, n, ng" (*Standard Dictionary*).

**Photography of the Larynx.**—Prof. Thomas R. French, of the Long Island College Hospital, has brought laryngeal photography to a high state of perfection, and has demonstrated most thoroughly the changes which take place in the vocal bands during the act of singing. The results of his observations are recorded in the *New York Medical Journal*. To him we are indebted for our present knowledge of this important subject, and from his articles in this publication we quote freely; the illustrations are also taken from the same source.

In photographing the larynx, Prof. French uses the electric arc light. The apparatus is shown in Fig. 217. It consists of an automatic 2000-candle-power lamp partly inclosed in a metal box. The front face of the box carries a condensing lens which, when placed 9 inches from the arc, gives a focal distance of 20 inches. This relation of light and lens is found to give the most satisfactory illumination. The lamp and accessories are fitted to a narrow board which is placed upon a table of sufficient height. The light can be raised or lowered by means of a device designed for that purpose. The rheostat is placed upon a shelf beneath the table top. The whole light outfit is but a modification of the electric stereopticon. This one is so arranged that by adding a second

FIG. 217.—Showing the manner in which photographs of the larynx and posterior nares are secured with the aid of the arc light.

condensing lens and an objective lens to the end of the cone-shaped tube in front it can be used as a projecting lantern.

In speaking of the action of the glottis, Prof. French says that with all his experience he has not yet permitted himself to formulate a theory of the action of the glottis in singing, for even now, after a large number of studies have been made, the camera is constantly revealing new surprises in the action of the vocal bands in every part of the scale. The movements of the larynx in a much larger number of subjects must be revealed, grouped, and recorded before definite conclusions can be drawn.

Most of our past knowledge on the subject of the changes in the larynx during singing has been obtained from inspection of this organ through the laryngoscope. As these changes follow each other too rapidly to be appreciated by the eye, much of this knowledge has been found to be erroneous. The photographic

plate, however, is so sensitive that every detail can be recorded, and as a result of its application to the physiology of the larynx, much that was regarded as established has been demonstrated to be false: just as the older ideas of the form of a lightning-flash have been entirely changed by instantaneous photography.

The difficulties to be overcome in photographing the larynx so as to show the changes during voice-production are many, among

FIG. 218.—Apparatus used in photographing the larynx.

them being the fact that it is only in certain individuals that the vocal bands can be seen throughout their whole length. This is very well shown in Fig. 220. In No. 1 the insertions of the vocal bands into the thyroid cartilage are so exposed as to be susceptible of being photographed; in No. 2 these are covered by the anterior wall of the larynx, and it would therefore be impossible to determine in such a larynx whether the vocal bands were lengthened or shortened in passing from one register to another,

or during a change in the pitch of the voice. In some individuals the bands will be exposed throughout their length while some notes are being sung, while during the singing of others they will be covered. Fig. 221 shows this; while singing F sharp and D, the bands are exposed, but covered when E is being sung. The number of persons whose larynges are so constructed as to permit photographing to determine the changes taking place in the glottis

FIG. 219.—Photograph taken by Prof. French of a normal larynx in quiet respiration.

throughout all the registers is, it will be seen, limited, and who they are can only be ascertained by careful inspection. Nor are the changes which take place the same in all individuals.

The following photographs show these changes in the larynx of a well-known professional contralto singer, and their explanation will be given in Prof. French's words:

No. 1.

FIG. 220.—PAIR 1.

No. 2.

"The voice in this singer is of excellent quality. The first of the pair (Fig. 222, No. 1) was taken while F sharp, treble clef, third line below staff, was being sung, and the second (No. 2) while she was singing E above. All notes in this and the following series were sung in the key of A. These are one of the lowest and the highest notes of her lower register. In the photograph representing the lowest note it can be seen that the vocal bands are quite



short and wide, and that, with the exception of the anterior fourth, the ligamentous and a part of the cartilaginous glottis is open and the slit between the vocal bands is linear in shape. As the voice ascends the scale the vocal bands increase in length and decrease in width, until at the highest note of the register they can be seen to have become considerably longer. It can also be observed that the ligamentous portion of the glottis is still open to the same relative extent, and that the cartilaginous portion has opened to its full extent. In the photograph representing the lower note the anterior faces of the arytenoid cartilages can be seen. As the voice ascended, the capitula Santorini were tilted forward. This seems to be proved



FIG. 221.

by the change in the position of these structures as seen in the photograph representing the upper note, as well as a similar change to be seen in nearly all the series showing the registers which I have taken. The epiglottis, though not well illuminated, seems to have risen as the voice ascended the scale. The light upon the epiglottis is so weak that the structure does not appear at all in the photo-engraving. The vocal bands have increased in length at least  $\frac{1}{8}$  inch in 7 notes. The compass of the voice of this sub-

ject is about  $2\frac{1}{2}$  octaves. Therefore, at that rate of lengthening, the vocal bands would increase nearly  $\frac{1}{2}$  inch if their length was progressively increased while singing up the scale from the lowest to the highest note. This progressive increase in length does not,



No. 1.

FIG. 222.—PAIR 2.

No. 2.

however, occur, and the reason is apparent in Fig. 223, which shows the changes which took place in the larynx at the lower break in the voice, which, in this subject, occurs at F sharp, treble clef, first space.



No. 1.

FIG. 223.—PAIR 3.

No. 2.

“The changes which occur at this point are extremely interesting and instructive. In the transition from the lower to the middle register, from E to F sharp, in the voice of this subject, the vibratory portions of the vocal bands are shortened about  $\frac{1}{18}$

inch. The anterior insertions of the vocal bands can be seen in both photographs; therefore the actual difference in the length of the bands can be appreciated. The vocal bands have not only become shorter, but they appear to be subjected to a much higher degree of tension. The cartilaginous glottis is closed and the aperture in the ligamentous portion has been much reduced in size. The laws which govern the pitch in both string and reed instruments will aid us in explaining these changes. Though the tone is higher and the degree of stretching less than in the note below, the tension is increased, and the aperture through which the air passes is much narrower. It seems to me that this clearly defined change in the mechanism of the vocal bands—which, so far as my investigations permit me to judge, are at this point in the scale the rule—will assist us to a clear understanding of the action of the laryngeal muscles in singing when we reach that part of the study.

“In the first photograph, which was taken while the subject was singing the note immediately preceding that on which the break occurred, the vocal bands can be seen to be long and wide and the posterior three-fourths of the chink of the glottis is open. By *open*, I mean that the edges of the vocal bands are not in actual contact. The anterior fourth or fifth of the ligamentous portion of the glottis is closed. The space between the vocal bands is widest in the cartilaginous portion of the glottis. In the production of the next note higher, F sharp, the second of the pair, a marked change in the size of the larynx and in the length of the vocal bands is seen to have occurred. The cavity of the larynx has been suddenly reduced in size and the vocal bands have been shortened. The cartilaginous portion of the glottis is closed and the ligamentous portion is open in a linear slit from the posterior vocal process to within a short distance of the anterior insertions of the vocal bands. The decrease in the length of the vibratory portions of the vocal bands is due to the closure of the cartilaginous glottis, for the ligamentous glottis remains about the same as in the note before the break. The arytenoid cartilages have been brought much closer together and occupy a more posterior position. These pictures were taken one after the other in quick succession, the conditions in every respect, except the note sung, being the same. The anteroposterior and lateral dimensions of the cavity of the larynx are shown to have been considerably decreased when the voice broke into the register above. When the mechanism of the larynx was changed the voice acquired a very different quality, which continued, in gradual elevation of pitch, throughout the register. As marked a change as this in the mechanism of the vocal bands in females is, I believe, found only in the larynges of contralto singers.

“It is believed by many writers on the voice that with the

change in the mechanism of the vocal bands the epiglottis is raised higher than in the register below. I am of the opinion that it is usually depressed. The reason for this belief is that, with very few exceptions, I have found it lower in the photographs showing the change than in those representing the note preceding it. When the voice of this subject broke into the middle register it was with difficulty that I could get the epiglottis to rise as high as it is shown here, which, though high enough to show the anterior insertions, is not so high as it was before the break. There does not seem to be any difference in the width of the vocal bands, but in this particular the appearances vary, the variation being due to the position of the ventricular bands. The entire upper surfaces of the vocal bands are rarely exposed to view during the production of the middle and upper notes.



No. 1.

FIG. 224.—PAIR 4.

No. 2.

“As this singer ascends the scale above the break at F sharp, the vocal bands are increased in length and the chink gradually enlarges, as shown in Fig. 224. The first photograph is of the larynx while singing F sharp, treble clef, first space, the note on which the lower break occurred, and the second while singing D, treble clef, fourth line, which is the highest note in the middle register of the voice of this singer. The difference in the length of the vocal bands and width of the chink of the glottis, as the voice mounts from the lowest to the highest note of the middle register, is clearly shown. Not only is it shown that the vocal bands increase in length as the voice ascends the scale, but the cartilaginous portion of the glottis—which, while producing the lowest note of this register, is seen to be tightly closed—has begun to open again, as shown by the small triangular opening which has appeared between the arytenoids in the second of this

pair. Again, as the vocal bands increase in length in this register their tension is apparently decreased. The capitula Santorini, which in the photograph representing the lowest note in the middle register are seen to be close together and occupy a position well backward in the laryngeal image, become more and more separated and are tilted more and more forward in the ascent of the scale.

"Now the voice mounts one note higher—that is, to E, treble clef, fourth space—and as it does so a distinct change in the quality of the voice is heard, and the second change in the mechanism of the vocal bands occurs. The changes which take place in the larynx at the upper break in the voice of this singer are shown in Fig. 225. The first of the pair represents the larynx while singing D, treble clef, fourth line, the note immediately preceding the



No. 1.

No. 2.

FIG. 225.—PAIR 5.

break, and the second shows the change which occurred while singing E, the next note above. A very decided change in the mechanism of the vocal bands is apparent. These ligaments have grown shorter and narrower, and the chink, which in the note before the break can be seen to be linear in shape and quite wide, after the break becomes considerably reduced in both length and width. Not only is the cartilaginous portion of the glottis closed in the note after the break, but also a small portion of the ligamentous glottis adjoining it. The chink appears to be closed to the same extent in front as it was while producing the note immediately preceding. There is, therefore, stop-closure in front and behind, which leaves a slit in the middle of the glottis measuring a little more than half the length of the vocal bands. In addition to these changes it may be observed that the epiglottis is depressed and the arytenoid cartilages have again receded. As

this is the highest note which this subject is capable of singing with ease, we cannot study the action of the vocal bands in the production of tones in the upper register.

"It may be remembered that in this larynx the vocal bands increased in length from the low F sharp to the E above. At the next note above they were suddenly shortened. At the next note higher they began to increase in length again, until D, above, was reached, and at E, the note next above, they were again suddenly shortened. It will be instructive to determine the degree to which the vocal bands were lengthened and at what point in the scale they were longest. We saw that in the lower register the vocal bands were longest in the production of the highest note, and in the middle register they were also longest while the highest note was being sung. By comparing the photographs representing these notes (Fig. 226) it can be seen that the vocal bands were as long, if not the longest, while the highest note of the lower register was being sung. In this subject the vocal bands increase in length in each register, but they attain as great a length in the lower as in either of the registers above, if not greater. It is generally thought that the pitch is raised by the vocal bands increasing progressively in tension and length. In regard to length this is true in some cases, while in others it is only true as applied to a register, not to the whole of the voice.

"The next series of photographs (not here reproduced) are of a professional singer who possesses a rich contralto voice of large range and good volume. The photographs of the larynx of this subject are strong enough for satisfactory exhibition upon the screen, but too weak for reproduction by the photo-engraving process. Though this singer has as large a range as she whose larynx we have just investigated, the pitch of her speaking voice is several tones higher. Here we shall find that the larynx acts in a very different way from that just examined. The first photograph of this pair was taken while F sharp, treble clef, third line below staff, was being sung; the second, while she was singing D, treble clef, first space below staff. The right arytenoid cartilage overlaps its fellow. In the production of the low note the anterior insertions are covered, and we cannot, therefore, see how long the vocal bands really are. The ligamentous portion of the glottis is well open, the chink being much wider behind than in front. The cartilaginous glottis appears to be closed, but I do not think that it really is, but, because of the somewhat unusual setting of the arytenoid cartilages, the cleft between them cannot be seen. As the voice ascends the scale the epiglottis is raised, the vocal bands increase in length, and the chink of the glottis gradually narrowed until at D, the highest note of the lower register, we find that the vocal bands appear to be considerably elongated, the chink considerably reduced in width, and the

epiglottis raised considerably higher. The cartilaginous portion of the glottis still appears to be closed, and there is no evidence of a forward movement of the capitula Santorini. When the next note higher was sung, a very noticeable change in the quality of the voice was heard, and, by examining the photographs taken while that note was being sung with that representing the note below it, it can be seen that a slight change in the mechanism occurred. The epiglottis is depressed. The vocal bands are longer and narrower, their edges are straighter, and the chink of the glottis, which in the note before the break was closed in front, has opened from the anterior to the posterior commissure, and is considerably increased in size. The cartilaginous glottis still appears to be closed. The arytenoid cartilage on the right side



No. 1.

FIG. 226.—PAIR 6.

No. 2.

occupies the same position as before the break, but the left has moved a little backward.

"The voice now ascends the scale until D, treble clef, fourth line, is reached, when it can be seen that the epiglottis is slightly raised, the vocal bands appear to be increased in length and decreased in width, and the arytenoid cartilages are turned further forward and brought closer together. The chink of the glottis is still open from front to back, and is altogether larger than in the lower note of this register. The apparent increase in the length of the vocal bands is partly due to the fact that the cartilaginous portion of the glottis is now beginning to open. This note is as high as this subject can sing with ease.

"In many particulars the action of this larynx is the reverse of that just examined. In this the cartilaginous glottis does not appear to begin to open until the highest notes are reached. In the lower register the chink of the glottis decreases instead of increases in size as the voice ascends. At the lower break the vocal

bands are increased instead of decreased in length, and the chink of the glottis is increased instead of decreased in size. In the larynx before examined the chink of the glottis increased in size and the vocal bands increased in length as the voice ascended in each register, attaining their greatest length at the highest note of the middle register; but in this the vocal bands attained their greatest length at the highest note in the voice of this subject, which corresponds to about the highest note of the middle register."

Figs. 227 and 228 are from photographs of the larynx of the contralto singer referred to on page 397, showing the same mechanism of the vocal bands in passing from the lower to the middle register, from E to F sharp, as is shown in Fig. 223, but on a different occasion.



FIG. 227.

FIG. 228.

In concluding his Berlin address, Prof. French says :

"Though the number of series of photographs which have been taken of the larynx in singing is quite large, I do not yet feel justified in drawing definite conclusions from them regarding many of the movements of the glottis at different points in the scale, but from the study made thus far the following conclusions regarding the glottis of the female may, I think, be safely drawn :

"1. The larynx may act in a variety of ways in the production of the same tones or registers in different individuals.

"2. The rule—which, however, has many exceptions—is that the vocal bands are short and wide and the ligamentous and cartilaginous portions of the glottis are open in the production of the lower tones; that, as the voice ascends the scale, the vocal bands increase in length and decrease in width, the aperture between the



posterior portions of the vocal bands increases in size, the capitula Santorini are tilted more and more forward, and the epiglottis rises until a note in the neighborhood of E, treble clef, first line, is reached. The cartilaginous glottis is then closed. The glottic chink becomes much narrower and linear in shape, the capitula Santorini are tilted backward, and the epiglottis is depressed.

“When the vocal bands are shortened in the change at the lower break in the voice, it is mainly due to closure of the cartilaginous portion of the glottis, the ligamentous portion not usually being affected. If, therefore, the cartilaginous glottis is not closed, there is usually no material change in the length of the vocal bands.

“As the voice ascends from the lower break, the vocal bands increase in length and diminish in width, the posterior portion of the glottic chink opens more and more, the capitula Santorini are tilted forward, and the epiglottis rises until, in the neighborhood of E, treble clef, fourth space, another change occurs.

“The glottic chink is then reduced to a very narrow slit, in some subjects extending the whole length of the glottis. In others, closing in front, or behind, or both. Not only is the cartilaginous glottis always closed, but the ligamentous glottis is, I believe, invariably shortened. The arytenoid cartilages are tilted backward and the epiglottis is depressed. As the voice ascends in the head register the cavity of the larynx is reduced in size, the arytenoid cartilages are tilted forward and brought closer together, the epiglottis is depressed, and the vocal bands decrease in length and breadth. If the posterior part of the ligamentous portion of the glottis is not closed in the lower, it is likely to be in the upper notes of the head register.”

## VITAL HEAT.

The temperature of a lifeless object is approximately that of the air which surrounds it; the temperature of a living object is independent of the temperature of the air, although it may be modified by it. This difference is due to the fact that living things produce heat within themselves; this is called “vital heat.” Many, perhaps most, authorities speak of it as “animal heat,” but, though it is most striking in members of the animal kingdom, yet inasmuch as its production is not confined to animals, but also occurs in plants, the writer prefers the term *vital heat* as indicating that the phenomenon is peculiar to the living condition, irrespective of the question whether it occurs in an animal or in a vegetable.

**Warm-blooded Animals.**—The term *warm-blooded* was applied to certain animals because their temperature was so high as to make them warm to the touch, while others were spoken of as *cold-blooded* because they were cold to the touch. Thus, man, with

a temperature of 37° C., the dog, 39°, the cat, 39°, the swallow, 44° or even higher, are among the warm-blooded, while reptiles and fishes, whose temperature is from 1.7 degrees to 4.5 degrees C. above that of the medium in which they exist, are cold-blooded. The terms warm-blooded and cold-blooded are, however, now not so frequently used as formerly, but in their stead are used the terms *homoiothermal* and *poikilothermal*.

**Homoiothermal animals** are animals of uniform heat or those whose temperature is unvarying. The thermometer if introduced into the rectum of a man, whether he is in the tropics or in the frozen regions of the North, will register about 38° C. The temperature of the surface of his body varies with that of the air—a fact with which all are familiar—but the internal temperature is the same irrespective of whether it is winter or summer. What is true of man is true also of other mammals and of birds—that is, of those animals commonly denominated warm-blooded.

**Poikilothermal animals** are animals of varying heat, or those whose temperature varies according to that of the medium—air or water—in which they live. The frog's temperature is slightly above that of the water, and if this is warm, the temperature in the frog will rise, to fall again when the temperature of the water is lowered. Thus a frog with a temperature of 20.7° C. in water at 20.6° C. will have a temperature of 38° C. when that of the water is raised to 41° C. Fishes, reptiles, amphibia, and insects also exhibit this same variation of temperature, so that cold-blooded and poikilothermal are practically interchangeable terms. A study of insects shows that these creatures produce heat, the thermometer registering, in some experiments on butterflies in active motion, a temperature of 5 degrees C. above that of the air. These insects are poikilothermal. The same power of generating heat is observed also in plants. The amount of heat varies under different circumstances, being especially marked at the time of germination and flowering, sometimes from 5 degrees to 10 degrees C. above that of the air.

**Temperatures of Different Animals.**—The following table gives the temperatures of some of the more common animals :

<i>Mammals.</i>	<i>Birds.</i>	<i>Poikilothermal animals.</i>
Centigrade.	Centigrade.	Temperature above surrounding medium.
Sheep . . 37.3°–40.5°	Duck . . . 42.5°–43.9°	Frog . . 0.32– 2.44 degrees C.
Ape . . . 35.5°–39.7°	Turkey . . 42.7°	Snakes . 2.50–12.0 degrees C.
Dog . . . 37.4°–39.6°	Chicken . 43.0°	Fish . . 0.50– 3.0 degrees C.
Horse . . 36.8°–37.5°		
Ox . . . 37.5°		

**Temperature of Different Parts of the Human Body.**—The temperature of the skin at the middle of the upper arm is 35.4° C., while in the sole of the foot it is but 32.26° C. In the

axilla it is about  $37.1^{\circ}\text{C.}$ , although some observers have placed it as low as  $36.25^{\circ}\text{C.}$ , and others as high as  $37.5^{\circ}\text{C.}$ ; under the tongue, about  $37.5^{\circ}\text{C.}$ ; and in the rectum about  $38^{\circ}\text{C.}$  The temperature of the liver, about  $41.39^{\circ}\text{C.}$  in the sheep, is regarded as the highest in the body: and higher here during digestion than in the intervals. The mean temperature of the blood may be stated as  $39^{\circ}\text{C.}$  The temperature of the muscles is increased in contraction 1 degree C. Mental exertion also increases the production of heat. After such exertion the temperature of the body has been found to be 0.3 degree C. higher than before.

**Temperature at Different Ages.**—The temperature of the child just born is  $37.86^{\circ}\text{C.}$  (rectum); in twenty-four hours,  $37.45^{\circ}\text{C.}$  (rectum). From five to nine years of age it is  $37.72^{\circ}\text{C.}$  (rectum); from twenty-five to thirty,  $36.91^{\circ}\text{C.}$  (axilla); from fifty-one to sixty,  $36.83^{\circ}\text{C.}$  (axilla); and at eighty,  $37.46^{\circ}\text{C.}$  (mouth). The amount of heat produced in old people is less than that in the middle-aged, and they therefore need greater protection from the cold.

**Daily Variations in Temperature.**—The temperature of an individual is not the same at all times of the day. His lowest temperature is between 2 and 6 o'clock A. M.; it rises during the day, and at about 4 to 8 P. M. is at its height, falling again until it reaches the minimum in the early morning. Thus, in one set of observations, at 5 A. M. the thermometer registered  $36.6^{\circ}\text{C.}$ ; at 8 P. M.  $37.7^{\circ}\text{C.}$ ; and at 2 A. M. the following day,  $36.7^{\circ}\text{C.}$ , and, as shown by recent experiments of Benedict, a chart representing these variations undergoes but slight changes under varying conditions, the temperature reaching the minimum at 2 to 6 A. M., "independent of whether the subject is sleeping soundly and in the recumbent position, or whether he is awake and sitting, or even standing and walking." In these experiments no tendency to an inversion of the temperature-curve by inverting the daily routine of life was observed. If the temperature is taken every hour during a day, the mean of the readings is called the "daily mean," and is about  $37.13^{\circ}\text{C.}$  in the rectum.

**Remarkable Instances of High and Low Temperature.**—The lowest temperature which the writer has been able to find was  $24^{\circ}\text{C.}$  This was in a drunken person who recovered from his debauch. A case of myxedema is reported in the *London Lancet* in which, on the day previous to death, the temperature varied from  $19^{\circ}\text{C.}$  to  $25^{\circ}\text{C.}$  In the same journal is recorded a case of shock produced by a fall on the spine, in which the temperature fluctuated between  $47^{\circ}\text{C.}$  and  $50^{\circ}\text{C.}$ , and for seven weeks did not fall below  $42^{\circ}\text{C.}$

The following case, recorded in the *Brooklyn Medical Journal*, illustrates the remarkable variations of temperature which may take place in a few hours. The patient was a man aged forty-eight; the diagnosis of the case was intermittent fever. He had been treated two or three months before for delirium tremens.

He left the hospital, became partially paralyzed, and then developed fever, his temperature rising to  $42^{\circ}$  and  $45^{\circ}$  C.; May 1, at night, it was  $44^{\circ}$  C.; May 2, in the morning,  $37^{\circ}$  C.; May 4, 2 A. M.,  $44^{\circ}$  C. He had chills, and was treated for malaria. After May 17, he had no rise of temperature. He was a wreck from alcohol.

**Heat-unit.**—The standard of measure of heat is the heat-unit or *calorie*. It is the amount necessary to raise the temperature of 1 gram of water  $1^{\circ}$  C. This is called the *small calorie*, to distinguish it from the *kilocalorie* or *kilogramdegree*, which is equal to 1000 small calories, and represents the amount of heat necessary to raise the temperature of 1 kilogram (liter) 1 degree C. It is estimated that an average man produces daily from 2200 to 3000 kilocalories, which is about 100 kilocalories per hour. During active exercise this amount is greatly increased, even to the amount of 3000 kilocalories hourly, while during sleep it may be but 40 kilocalories.

**Sources of Vital Heat.**—The sources from which the heat of the body is derived are numerous. Among them are :

1. *The Oxidation of the Food-stuffs.*—The oxidation of carbohydrates and fats results in the production of  $\text{CO}_2$  by the oxidation of the carbon, and of  $\text{H}_2\text{O}$  by that of the hydrogen ; while from the proteids are formed by the same process  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ , urea, and certain extractives. This oxidation may take place with the result of producing heat, or it may result in the production of some other form of energy, as the contraction of muscles ; but whatever form it may take, the ultimate products of oxidation are the same. Fat burned outside the body and fat burned (oxidized) inside the body will produce the same amount of heat. If, therefore, the chemical composition of the food-stuffs is known, and also that of the products of their oxidation when eliminated from the body, it is a simple matter to calculate the heat-value of any food. Chemists have ascertained that the oxidation of 1 Gm. of carbon to  $\text{CO}_2$  produces 8080 calories ; and of the same amount of hydrogen to  $\text{H}_2\text{O}$ , 34,460 calories. The oxidation of 1 gram of carbohydrate, as starch, to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  results in the production of 4116 calories, and of fat, 9312 calories. Carbohydrates and fats are completely oxidized in the body, not with the direct and immediate production of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  ; but though there are many intermediate stages, still the ultimate results are the same as when the oxidation takes place outside the body.

Proteids, on the other hand, are not completely oxidized in the body, for, as we have seen, the products of their oxidation are mainly  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ , and urea ; but urea is still further oxidizable. This oxidation does not occur in the body, as urea is eliminated as such ; hence in estimating the heat-value of proteids we must deduct that of urea. The complete oxidation of 1 gram of proteid to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  produces 5778 calories, but we must deduct from this the heat-value of the urea produced in their oxidation. One

gram of urea oxidized gives 2523 calories; the oxidation of 1 gram of proteid produces  $\frac{1}{3}$  gram of urea; hence from the 5778 calories produced by the complete oxidation of the proteid we must deduct 841 calories, which gives 4937 calories as the actual heat-value of 1 gram of proteid.

If now we recall the adequate diet of Moleschott (p. 130), we shall find that the amount of heat-production in twenty-four hours with such a diet is 2,801,148 calories, calculated as follows:

	Grams.		Calories.		Calories.
Proteids . . . . .	120	×	4937	=	592,440
Fats . . . . .	90	×	9812	=	838,080
Carbohydrates . . . . .	333	×	4116	=	1,370,628
					<hr/> 2,801,148

It must not be inferred from the above statement that all the food taken into the body is oxidized and reappears in the form of energy, for, as we have seen, a not inconsiderable part passes out from the body without having undergone the digestive process.

Although oxidation is the great source of the heat produced in the body, there are doubtless contributory causes, such as (2) the various movements which take place, producing heat by *friction*; also (3) *electricity* generated in muscles and nerves; but of the amount produced by these and other physical causes we know but little.

**Channels through which Vital Heat is Lost.**—Helmholtz estimates that 7 per cent. of the total heat produced in the body is expended in the form of mechanical work; that 78 per cent. is discharged through the skin by evaporation and radiation; and 15 per cent. by the lungs, urine, and feces.

Vierordt calculates that the heat discharged from the body is distributed as follows:

	Calories.
1.8 per cent. in urine and feces	= 47,500
8.5 per cent. in expired air	= 84,500
7.2 per cent. in evaporation of water from lungs	= 182,120
14.5 per cent. in evaporation of water from skin	= 364,120
73.0 per cent. in radiation and conduction from skin	= 1,791,820
	<hr/> 2,470,060

**Calorimetry.**—A calorimeter is an apparatus for determining the amount of heat dissipated or disengaged from any substance or from a living animal. Those used for animals consist of a chamber adapted to hold the animal, surrounded by some medium which will absorb the heat, such as ice, air, or water.

**Dulong's calorimeter** consists of a chamber in which the animal is placed; this is contained in a larger chamber holding water. Outside of this is a layer of some non-conducting material, like wool, and outside of all is a box. Air from a gasometer is admitted on one side, and the expired air passes out on the other.

**Reichert's water calorimeter** (Fig. 229) is described by its in-

ventor as consisting of "two concentric boxes of sheet metal which are fastened together so that there is a space of about  $1\frac{1}{2}$  inches between them, filled with water. The water box is 15 inches in height and width, and 18 inches in length. An opening (*h*) 9 inches in diameter is made in one end for the entrance and exit of the animal. It is also perforated with three small holes in the top corners, and a slit-like opening in the top on one side. Two of the holes are for the tubes for the entrance and exit of air (*EN*, *EX*), the entrance tube being carried close to the bottom, while the exit tube extends only to the top of the box, and is placed in the opposite diagonal corner, thus ensuring adequate ventilation. In the third hole a thermometer (*CT*) is inserted, by means of which the temperature of the calorimeter (jacket of metal and water) is obtained. The opening in the side is for the insertion of a stirrer (*S*), which is for the purpose of thoroughly mixing the

FIG. 229.—Reichert's water calorimeter.

water and thus equalizing the temperature of both water and metal—in other words, of the calorimeter."

Before using the apparatus to determine the heat dissipated by an animal, the *calorimetric equivalent* is determined—i. e., the amount of heat necessary to raise the temperature of the calorimeter 1 degree C. One gram of alcohol burned produces 9000 calories of heat. If the burning of 10 grams raises the temperature of the calorimeter 1 degree C., then the calorimetric equivalent will be

90,000 calories or 90 *kilogramdegrees*—i. e., for each degree of increase in the temperature of the apparatus 90 *kilogramdegrees* are absorbed.

Besides the heat which is absorbed by the calorimeter, additional amounts are given off by the subject of the experiment in its expired air, and expended in evaporation of the water from its lungs and skin. To ascertain these, the amount of air supplied and its temperature on entering and leaving the instrument must be determined, also the amount of water in the air.

**Air calorimeters** are also used, such as that of Haldane, Hale White, and Washbourn (Fig. 230). In this instrument the animal is placed in the chamber C, and hydrogen is burnt in H. The tubes A A and A' A' being closed, the heat dissipated by the animal expands the air in the air-space between the walls of the chamber, and increases the pressure on that side of the fluid in the manometer M, causing it to move toward H. The flame of hydrogen is regulated so that the amount of heat which is produced by its combustion counterbalances that of the animal and keeps the fluid in the manometer stationary. From the amount of water produced the amount of hydrogen burnt is calculated, and

FIG. 230.—Diagram of air calorimeter: F, layer of felt; A, tubes for ventilation; C, cage; H, hydrogen flame; M, manometer (Haldane, Hale White, and Washbourn).

the number of calories produced by its burning is determined, which equals that given off from the animal.

Although there are produced in the adult human body between 2000 and 3000 kilocalories of heat daily (p. 409), still this is very materially affected by various conditions. Thus, children produce proportionately more than adults; strong, than weak persons; fleshy persons, than those who are thin.

Diet is another very important factor, as shown by the following table (Danilewsky), giving the amount of heat produced under different diets:

On a minimum diet . . . . .	1800 <i>kilogramdegrees</i> .
On a reduced diet (absolute rest) . . . . .	1989       “
On a non-nitrogenous diet . . . . .	2480       “
On a mixed diet (moderate work) . . . . .	3210       “
On an abundant diet (hard work) . . . . .	3646       “
On an abundant diet (very laborious work) . . . . .	3780       “



**Regulation of Temperature.**—When the temperature of the muscles is raised to  $49^{\circ}$  C. they lose their contractility. This figure has been regarded as the highest that can be reached by a living human being; indeed, much below this,  $45^{\circ}$  C., has long been considered as fatal, although a temperature of nearly  $52^{\circ}$  C. has been recorded. When the temperature falls to  $19^{\circ}$  C. a fatal result will follow.

To prevent the body from becoming too hot is one of the functions of the skin. This it accomplishes by radiation, conduction, and evaporation. Of the total heat given off from the body, 73 per cent. is by radiation and conduction from the skin, and 14.5 per cent. is by evaporation. Thus there is carried off by the skin nearly 88 per cent. of the total heat. This topic will again be discussed in the consideration of the skin and its functions.

The prevention of the reduction of the temperature of the body to an extent that would be harmful is accomplished by wearing proper clothing, by the ingestion of food, both solid and liquid, by warming the air which comes in contact with the body, and by increased muscular activity. The use of alcohol for this purpose is, as previously stated, delusive.

## THE SKIN.

The skin is composed of a deep portion, the corium, derma, or true skin; and of a superficial portion, the epidermis or cuticle.

**Corium.**—The corium makes up by far the greater part of the skin, and within it are the perspiratory glands, the sebaceous glands, the hairs, together with both blood- and lymphatic vessels. The upper surface, where it joins the epidermis, is irregular, being composed of elevations—papillæ—and intervening depressions. In some of these papillæ are the tactile corpuscles, in which nerve-fibers end.

**Epidermis.**—The epidermis is made up of a deep and a superficial layer. The deep layer (rete mucosum or rete Malpighii) covers the papillæ of the corium and fills the depressions between them. It is composed of cells, round or of different shapes due to pressure of contiguous cells, the material of which they are composed yielding readily. It is in this layer that the pigment is deposited which characterizes the dark races. The superficial layer of the epidermis is composed of cells which are flat and dry or horny.

**Perspiratory Glands.**—The perspiratory glands, also described as sweat- and sudoriparous glands, are very numerous, it being estimated that in the entire skin there are not less than 2,400,000. They are more abundant in some parts of the body than in others: in the palm of the hand there are 42 to the square centimeter; on the forehead, 190; and on the cheek, 85. If all



these glands in the body were straightened out and put end to end, they would extend a distance of 4 kilometers.

This brief consideration of the perspiratory glands suggests that their function must be very important. They are constantly at work pouring out their secretion upon the surface of the skin. Ordinarily this secretion is not perceptible, and it is then called "insensible perspiration." Upon active exercise or when the temperature of the air is high this secretion becomes visible, and it is then called "sweat" or "perspiration." The average total amount daily formed is 900 grams. This amount is subject to

FIG. 231.—Vertical section of the skin, diagrammatic (after Heitzmann).

considerable variations, being increased in summer and diminished in winter. During violent exercise the amount may be as much as 380 grams per hour, and during exposure to very high temperatures it has been known to reach 1814 grams in the same time.

Sweat has a salty taste, a specific gravity of 1003 to 1005, and is acid in reaction. It is claimed by some writers that its true reaction is alkaline, and that its acidity is in reality due to the

presence of fatty acids resulting from the decomposition of the sebum. In uremia the amount of urea may be so great as to crystallize on the skin; in diabetes sugar may be found in the sweat; and in cases of gout uric acid has been detected.

The following table shows the composition of sweat:

Water . . . . .	99.00 per cent.
Urea . . . . .	0.15 "
Neutral fats, fatty acids, cholesterin, sodium and potassium chlorida, and other salts . . . .	0.85 "
	<hr/> 100.00

**Office of Perspiration.**—One of the important means of regulating the temperature of the body is the perspiration. Without it,

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FIG. 232.—*c*, Corneous (horny) layer; *g*, granular layer; *m*, mucous layer (rete Malpighii). The stratum lucidum is the layer just above the granular layer. Nerve-terminations: *a*, afferent nerve; *b*, terminal nerve-bulbs; *l*, cell of Langerhans (after Ranvier).

exposure to high temperatures would be injurious, and in some cases would even be fatal. An external temperature of 52° C. is not infrequently met with in the southern part of the United States; to this heat human beings are exposed without suffering from its effects. The evaporation of the perspiration abstracts heat from the body. Of the heat given off from the body, 88 per cent. passes off by the skin; of this amount, 73 per cent. is by radiation and conduction, and 14.5 per cent. by evaporation.

**Sebaceous Glands.**—The sebaceous glands are racemose glands, and discharge their product—*sebum*—into the hair-follicles of large hairs, as upon the scalp, while in other portions of the body, as the forehead, where the hairs are small, the hair projects from the mouth of the sebaceous gland, and is more like an appendage than a separate structure.



FIG. 233.—C, Epidermis; D, corium; P, papillæ; S, sweat-gland duct; e, arterial and venous capillaries (superficial or papillary plexus) of the papillæ (deep plexus is partly shown at lower margin of the diagram), rs, an intermediate plexus, an outgrowth from the deep plexus, supplying sweat-glands and giving a loop to hair-papilla (after Ranvier).

**Composition of Sebum.**—The sebum, or sebaceous matter, is of an oily nature. It contains albumin, fat, and cholesterin. The *vernix caseosa* which covers the infant during the latter part of fetal life is of the same character, consisting principally of fat with epithelium. At the temperature of the body the sebum is fluid, but it solidifies on the surface of the skin. Its office is

mainly to keep the skin and the hairs soft and pliable. Besides this, it is probably excrementitious to a certain extent.

**Cerumen**, commonly called "ear-wax," is the product of the sebaceous and perspiratory glands of the external auditory meatus, and is composed principally of fat with some soap. It is a reddish substance having a sweetish-bitter taste.

**Hairs and Nails.**—These structures are modified epidermis. The hair grows from the hair-papilla, in the interior of which

b

c

e

f

1 f

FIG. 234.—A normal sweat-gland, highly magnified: a, sweat-coil, with secreting epithelial cells; b, sweat-duct; c, lumen of duct; d, connective-tissue capsule; e and f, arterial trunk and capillaries supplying the gland (after Neumann).

FIG. 235.—A normal sebaceous gland in connection with a lanugo-hair; greatly magnified: a, connective-tissue capsule; b, fatty secretion; c, h, fat-secreting cells; d, root of a lanugo-hair; e, hair-sac; f, hair shaft; g, acini of sebaceous gland (after Neumann).

there is a blood-vessel. The integrity of this papilla is essential to the existence of the hair; when destroyed, the hair can never be reproduced. It should be noted that the hair-papillæ and the papillæ already described in connection with the corium are very different structures, and should not be confounded. It has been estimated that there are, on an average, 120,000 hairs in the scalp. As a rule, the lighter the color of the hair the finer it is; in the female it is coarser than in the male.

**Functions of the Skin.**—The functions of the skin are numerous and very important.

(1) **Protection.**—The tissues which lie beneath the skin are delicate and sensitive, and are protected from injury by it. The epidermis, by reason of its hard and tough character, especially in the palms of the hands and on the soles of the feet, is peculiarly adapted to this end.

(2) **Excretion.**—It has already been noted that by the skin a liter of fluid is daily eliminated from the body. In this fluid are

FIG. 236.—A, Shaft of the hair; B, root of the hair; C, cuticle of the hair; D, medullary substance of the hair; E, external layer of the hair-follicle; F, middle layer of the hair-follicle; G, internal layer of the hair-follicle; H, papilla of the hair; I, external root-sheath; J, outer layer of the internal root-sheath; K, internal layer of the internal root-sheath (after Duhring).

dissolved materials representing the waste of the tissues. There is a reciprocal relation between the skin and the kidneys: in summer, when the skin is active, the amount of fluid passed off by the kidneys is reduced, while in winter, when the skin is inactive, the work of the kidneys is much increased. In diseased conditions of the kidneys, the retention in the blood of poisonous materials which are eliminated by them in health is prevented by causing the perspiratory glands of the skin to assume this function.

(3) **Sensation.**—The skin, especially at the tips of the fingers,

is very sensitive, and gives knowledge of the consistency of objects, also whether they are rough or smooth, sharp or dull, etc. This subject of general sensibility will be fully discussed in connection with the Nervous Functions.

(4) **Respiration.**—Interchanges are constantly taking place in the skin analogous to those which take place in the lungs, although to a much less extent. Oxygen is absorbed from the air by the blood in the cutaneous blood-vessels, and at the same time carbon dioxid is given off. In frogs these interchanges are much more extensive than in man.

FIG. 237.—a, A vascular papilla; b, a nervous papilla; c, a blood-vessel; d, a nerve-fiber; e, a tactile corpuscle (after Biesiadecki).

(5) **Regulation of temperature**, which has already been discussed (page 415).

**Care of the Skin.**—That the skin may perform its functions properly it must be taken care of. The orifices of the ducts of the perspiratory and sebaceous glands must be kept free, so that they may not become clogged. If the skin of an animal is covered with varnish, it speedily dies. This is not due to the retention of waste-materials, which act as poisons, but to the great loss of heat, in the rabbit the temperature falling to 20° C. Experiment has shown that if an animal that has been varnished is packed in cotton and kept in a temperature of 30° C., it will survive.

Gerlach covered a horse and a rabbit with linseed oil, with the following results :

Animal.	Temperature before.		Temperature after.		Remarks.
	Rectal.	Cutaneous.	Rectal.	Cutaneous.	
Rabbit . . .	39.7° C.	38° C.	28° C.	26° C.	{ At time of death, thirty hours after varnishing. On the sixth day after varnishing; death occurred on eighth day.
Horse . . .	38°	35°	32°	29°	

Reference is frequently made to the gilding of a child's body to make it represent an angel at the coronation ceremonies of Pope Leo X., which resulted in the speedy death of the child. Inasmuch as the whole human body has been covered by an impermeable layer for eight or ten days without producing any disturbance whatever, even in the body-temperature, it is probable that there was something in the gilding material which acted as a poison. The ability of the human being to regulate his temperature explains the different result in man and in the horse and rabbit.

The skin requires both friction and bathing to maintain it in a physiologic condition. The process of rubbing removes the useless epidermic scales and any obstructions which tend to clog the mouths of the glands. The oily nature of the sebaceous matter, which is always present and which retains the dust and dirt coming in contact with it, requires that the skin be washed with water and soap. But the soap must be free from irritating ingredients, such as rancid fat, and from too large an amount of alkali and coloring-matter, and from drugs of various kinds. If the skin is diseased, medication by means of soap may be needed, but it should be prescribed by a physician. If the skin is not diseased, medicated soaps are harmful. Old white Castile soap meets all the indications in health.

**Baths.**—Baths may be classified as follows :

Cold bath . . . . .	0° to 24° C.
Temperate bath . . . . .	24° to 26° C.
Tepid bath . . . . .	26° to 32° C.
Warm bath . . . . .	32° to 37° C.
Hot bath . . . . .	37° to 44° C.

As a rule, hot baths are relaxing, and should not, therefore, be indulged in too frequently; indeed, in persons suffering with disease of the heart they may actually endanger life. The Turkish bath, taken under competent medical supervision, is often of great benefit, and many persons take it weekly, and even oftener, with the effect of toning up the system and making them more competent to endure both physical and mental fatigue. Cold baths, except for the very robust, are also to be taken with great caution. If afterward there is reaction and if the skin becomes warm and pink, they are beneficial, but if the skin becomes cold and blue, they are injurious. In fact, this should be the test for each indi-

vidual to apply to his own case. Bathing, except a sponge- or plunge-bath, should not be practised when the vital powers are low, as early in the morning, nor after a long fast, nor should it be indulged in too soon after eating; eleven o'clock in the morning is, for the average person, a proper time for a bath of considerable duration.

### THE URINARY APPARATUS.

The **kidneys** (Fig. 238) are situated in the lumbar region of the abdominal cavity, one on each side of the spinal column, with the upper border on a level with the twelfth dorsal, and the

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FIG. 238.—Longitudinal section through the kidney: 1, cortex; 1', medullary rays; 1'', labyrinth; 2, medulla; 2', papillary portion of medulla; 2'', boundary layer of medulla; 3, transverse section of tubules in the boundary layer; 4, fat of renal sinus; 5, artery; \*, transverse medullary rays; A, branch of renal artery; C, renal calyx; U, ureter (after Tyson and Henle).

lower opposite the third lumbar vertebra. The dimensions of each are approximately: Length, 10 cm.; breadth, 5 cm.; thickness, 2.5 cm. The weight is from 125 to 180 grams.

The shape of the kidney is like that of a bean, the internal



border being concave and presenting a fissure—the *hilum*—at which the vessels, the nerves, and the ureter enter the organ. When the kidney is longitudinally cut in two, it is seen to be made up of an external or cortical portion—*cortex*—and an internal or medullary portion—*medulla*. The medullary portion is made up of numerous pyramids (those of Malpighi), from 8 to 18 in number, and, dipping down between them, as well as forming the outer part of the kidney, is the cortical portion. Each pyramid terminates in a *papilla* projecting into a *calyx*, which, with the calices of other pyramids, forms the *pelvis*, the upper dilated cavity of the ureter.

**Tubuli Uriniferi** (Figs. 239, 240).—At each papilla there open about 20 uriniferous tubules, which can be traced to the base of the pyramid. Each tubule continues into the cortical portion of the kidney, where it is larger and becomes convoluted, narrowing again and entering the pyramid, in which it again becomes straight, forms a loop, and re-enters the cortical portion, again becomes convoluted, and finally terminates in a spherical body, the *Malpighian capsule* or *capsule of Bowman*.

**FIG. 239.**—Diagram of two uriniferous tubules: 1, Malpighian tuft surrounded by Bowman's capsule; 2, constriction or neck; 3, proximal convoluted tubule; 4, spiral tubule; 5, descending limb of Henle's loop; 6, Henle's loop; 7 and 8, ascending limb of Henle's loop; 9, wavy part of ascending limb of Henle's loop; 10, irregular tubule; 11, distal convoluted tubule; 12, first part of collecting tube; 13 and 14, straight part of collecting tube; 15, excretory duct of Bellini (Tyson and Brunton, after Klein and Noble Smith).

This complicated structure may, perhaps, be traced more easily in the opposite direction. Beginning with the Malpighian capsule in the cortical portion, there is next the convoluted tubule, which, as it passes into the medullary portion, becomes straight and is known as the "descending limb of Henle's loop." This bends on itself, forming the ascending limb, likewise straight, passes back into

the cortex, becomes convoluted, and enters a straight collecting tube which opens at the apex of a pyramid.

The uriniferous tubules are lined with epithelium, which varies at different parts of their course. The epithelium which lines the capsules and the neck, and which covers the glomerulus, is flattened,

**PLATE IV.**

*A, A*, right and left kidneys; *B*, urinary bladder; *C, C*, right and left ureters; *d, d*, renal arteries (MacLise).



and the cells have an oval nucleus (Fig. 241). This changes to a thick polyhedral epithelium, with a fibrillar or striated structure, in the proximal convoluted tubule and spiral tubule of Schachona. It is again flat in the descending limb of Henle's loop, while in the ascending limb it resembles that of the spiral tubule. The epithelium in the irregular or zigzag tubule is angular and markedly

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FIG. 240.—Diagrammatic scheme of uriniferous tubules and blood-vessels of kidney ; drawn in part from the descriptions of Golubew (Böhm and Davidoff).

striated ; in the second convoluted tube it is like that in the first ; in the junctional tubes, flat and cubical ; in the straight or collecting tubes, clear cubical and columnar ; and in the ducts of Bellini, clear columnar.

The following table, from Schäfer's *Essentials of Histology*, exhibits the differences in the epithelium of the tubules in a manner very useful for reference :

Portion of tubule.	Nature of epithellum.	Position of tubule.
Capsule . . . . .	{ Flattened, reflected over glomerulus.	Labyrinth of cortex.
First convoluted tube .	{ Cubical, fibrillated, the cells interlocking.	Labyrinth of cortex.
Spiral tube . . . . .	Cubical, fibrillated (like the last).	Medullary ray of cortex.
Small or descending tube of Henle . . . }	Clear flattened cells.	{ Boundary zone and partly papillary zone of medulla.
Loop of Henle . . . . .	Like the last.	Papillary zone of medulla.
Larger or ascending tube of Henle . . . }	{ Cubical, fibrillated, sometimes imbricated.	{ Medulla and medullary ray of cortex.
Zigzag tube . . . . .	{ Cells strongly fibrillated; varying height; lumen small.	Labyrinth of cortex.
Second convoluted tube	{ Similar to first convoluted tube, but cells are longer, with larger nuclei, and they have a more refractive aspect.	Labyrinth of cortex.
Junctional tube . . . .	Clear, flattened, and cubical cells.	{ Labyrinth passing to medullary ray.
Straight or collecting tube . . . . }	{ Clear cubical and columnar cells.	Medullary ray and medulla.
Duct of Bellini . . . .	Clear columnar cells.	Opens at apex of papilla.

**Blood-vessels.**—The renal artery (Fig. 238), which supplies the kidney, is a branch of the abdominal aorta, which before entering

FIG. 241.—From section of cortical substance of human kidney: *a*, epithelium of Bowman's capsule; *b* and *d*, membrana propria; *c*, glomerular epithelium; *e*, blood-vessels; *f*, lobe of the glomerulus; *g*, commencement of uriniferous tubule; *h*, epithelium of the neck; *i*, epithelium of proximal convoluted tubule;  $\times 240$  (Böhm and Davidoff).

the organ subdivides into 4 or 5 vessels. It is from these vessels that the suprarenal capsules and the ureter also receive their blood-supply. When, as frequently happens, there is a second artery, it is called the *inferior renal artery*.

The branches of the renal artery pass toward the cortex and end as proper renal arteries, *arteriæ propriæ renales*, from which are given off the *interlobular arteries* in the direction of the cortical substance, and the *arteriolæ rectæ* toward the medullary pyramids. From the interlobular arteries are given off the *afferent*

Nuclei of endothelial cells of blood capillaries.

Lumen of uriniferous tubule.  
Striated border.

FIG. 242.—Section of proximal convoluted tubules from man;  $\times 580$  (Böhm and Davidoff).

*vessels*, which pierce the capsules and end in the Malpighian tufts. From the capsules emerge the *efferent vessels*, which form a *venous plexus* about the uriniferous tubes, and the blood ultimately leaves the kidney by the renal vein.

**Nerve-supply of the Kidney.**—The nerves of the kidney, from 15 to 20 in number, have ganglia upon them, and are from the renal plexus. This plexus is formed from the solar plexus, semi-lunar ganglion, lesser and smallest splanchnic nerves. So far as known, the nerves are distributed to the arterioles principally,

though nerve-fibrils are described as ramifying among the epithelium of the tubules.

**Function of the Kidneys.**—The function of the kidneys is to form urine. This is sometimes spoken of as a *secretion*, but inasmuch as its constituents pre-exist in the blood when that fluid comes to the kidneys, and these organs simply remove these substances from the blood, urine is more properly an *excretion*. The ingredients composing the urine may, from a physiologic standpoint, be divided into two groups: (1) Water and some of the salts; and (2) urea, uric acid, and allied substances.

The first group, consisting of water and salts, is eliminated from the blood while that fluid is passing through the glomerulus within Bowman's capsule, the beginning of the uriniferous tubules; while the urea group is excreted while the blood is passing through the venous plexus surrounding the convoluted portions of the tubule.

**Excretion of Water and Salts.**—While all authorities agree that it is at the glomeruli that water and some of the inorganic salts are eliminated from the blood, there is a diversity of opinion as to the factors engaged in this process; some regarding it as a simple filtration in which the glomerular epithelium plays a passive part, while others attribute to these cells a very important part in the process. Whenever the renal blood-supply is increased, the quantity of urine is also increased, and it has therefore been assumed that this increase was due to the heightened blood-pressure within the glomerulus, and this is the basis of the filtration theory; but it has been pointed out that under these circumstances there is an increased blood-flow through the organ, and it is to this that Heidenhain attributes the increased secretion, rather than to the simple increase of pressure within the glomeruli. This authority is one of the principal exponents of the theory that the glomerular epithelium is the efficient agent in the elimination which takes place within Bowman's capsule.

*Bowman*, in 1842, advanced the opinion that "the Malpighian bodies might be an apparatus destined to separate from the blood the watery portion" of the urine. On the other hand, he held that "the tubes and their plexus of capillaries were probably the parts concerned in the secretion of that portion of the urine to which its characteristic properties are due."

In 1884 *Ludwig* expressed the opinion that all the constituents of the urine escape from the blood while passing through the glomeruli, and that this separation is due to the high pressure under which the blood is within these structures.

*Heidenhain* combated the view of *Ludwig* on various grounds: Among others, that a rise of arterial pressure elsewhere in the body, as in the salivary glands, does not cause increased transudation through the walls of the blood-vessels; that the epithelium

covering the glomeruli would offer great resistance to filtration; that if the renal vein is ligated and the pressure within the glomeruli thereby increased, not only is the flow of urine not increased, but it is actually abolished; and, finally, that filtration will not explain the increased flow of urine when water and crystalloid substances are increased in the blood. Heidenhain, as already stated, believes that the cells of the glomerular epithelium act as secretory cells do elsewhere, and by the power which they possess as living cells eliminate water and inorganic salts, especially sodium chlorid, from the blood.

In commenting on these opinions, Starling, to whose admirable article on "The Mechanism of the Secretion of the Urine," in Schäfer's *Text-book of Physiology*, we are much indebted, says: "It seems probable that in the glomeruli the process is largely if not exclusively physical," and that "we have at present no evidence that the cellular covering of the glomeruli acts otherwise than passively in the production of the glomerular part of the secretion." He also refers to the researches of Munk and Senator, who have reached the conclusion that water and part of the urinary salts, especially sodium chlorid, are transuded through the glomeruli in direct consequence of the blood-pressure—*i. e.*, by a process of filtration, although the rapidity of the blood-flow is equally important. It is also generally accepted that when serum-albumin, hemoglobin, or dextrose escapes from the blood and becomes a constituent part of the urine, this takes place while the blood is passing through the glomeruli.

The oncometer (p. 338) has been largely used in connection with the various experiments which have been conducted to determine the effects of increased and diminished blood-pressure on the excretion of urine by the kidney.

*Excretion of Urea, Uric Acid, etc.*—Bowman, in his views as to the manner of the formation of urine, expressed the opinion that the tubes and their plexus of capillaries were probably the parts concerned in the secretion of the substances forming this second group of urinary constituents, and this is the generally accepted view of the authorities of the present day. It is also probably true that some water, sodium chlorid, sulphates, and phosphates are eliminated from the blood in this part of its course through the kidney. The efficient agents in this elimination are the cells lining the tubules, and especially those in the convoluted portions.

**Effects of Removal of the Kidneys.**—Removal of a single kidney for a diseased condition of that organ, constituting *nephrectomy*, is not an uncommon operation at the present day. After the operation the remaining kidney enlarges and performs the functions of both. Removal of both kidneys is followed by a fatal result.



**Ureters.**—From each kidney passes a ureter, a tube which connects the kidney with the bladder, and through which the urine is discharged. It has a diameter about that of a goose-quill and a length of about 40.6 cm. It has 3 coats: External or *fibrous*; middle or *muscular*; and internal or *mucous*. The muscular tissue is of the plain variety and arranged in 2 layers: longitudinal and circular; a third layer, also longitudinal, is found near the bladder. The mucous membrane is covered with *transitional* epithelium (p. 34).

When the ureters reach the base of the bladder, they pass for about 2 cm. between the muscular and mucous coats, and then open by a constricted orifice in the bladder.

**Function of the Ureters.**—The urine which is being constantly formed by the kidneys passes into their pelves, and by peristaltic action of the muscular coat of the ureters is carried to the bladder, into which it flows intermittently. The actual entrance of the urine has been observed in a case of *ectopia vesicæ* in a boy. This condition consists in a deficiency in the abdominal wall and in the front wall of the bladder, so that the openings of the ureters

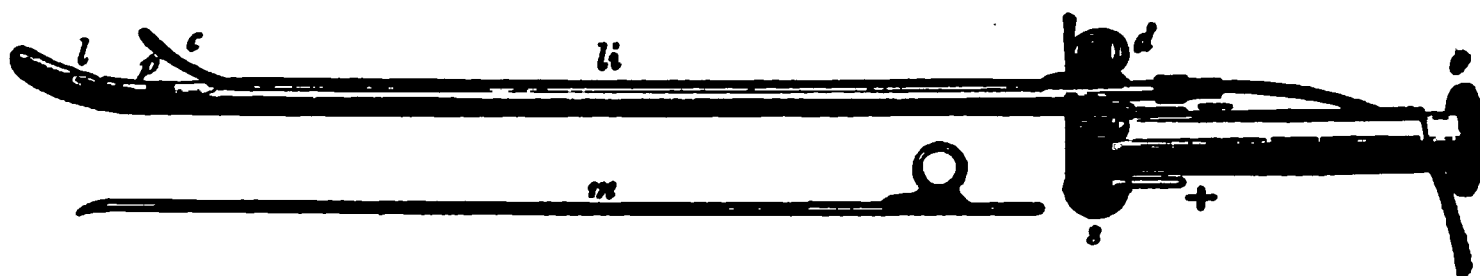


FIG. 243.—Casper's ureter cystoscope: *li*, movable lid covering groove in which moves *c*, the ureteral catheter; *d*, handle of lid; *o*, ocular end; *p*, prism; *l*, lamp, *s*, screw for making and breaking connection with the battery; *m*, mandril.

can be inspected. In this case the flow of urine into the bladder was intermittent, and about the same in amount for each ureter.

By means of the *cystoscope* (Fig. 243) it has been determined that the peristaltic action of the ureters is both intermittent and alternate; exceptionally it may be synchronous. At intervals of a minute or more urine is discharged from the ureters into the bladder, the amount varying; but averaging, perhaps, from 15 to 30 drops.

The cause of this peristaltic contraction is not definitely determined. Some authorities attribute it to the direct stimulation of the muscular tissue by the accumulated urine, which results in a wave which is propagated from one muscle-cell to another; while others think that this contractility of the musculature of the ureters is a power possessed by it independent of any direct stimulation, either mechanical or nervous. Experiments upon the rat have demonstrated that when the ureter is cut into several pieces, each section will contract peristaltically.

**Bladder** (Fig. 244).—This is not infrequently spoken of as the *urinary bladder*, and when moderately distended will contain about  $\frac{1}{2}$  liter; though it may be so distended as to contain very much more than this.

It has 4 coats: *peritoneal* or *serous*, *muscular*, *submucous*, and *mucous*. The muscular coat is made up of 3 layers of plain muscular fiber: External or longitudinal, middle or circular, and internal, which is also longitudinal. The external longitudinal layer is also described as the *detrusor urinae* muscle, and the aggre-

FIG. 244.—Section of penis, bladder, etc.: 1, symphysis pubis; 2, prevesical space; 3, abdominal wall; 4, bladder; 5, urachus; 6, seminal vesicle and vas deferens; 7, prostate; 8, plexus of Santorini; 9, sphincter vesicae; 10, suspensory ligament of penis; 11, penis in flaccid condition; 12, penis in state of erection; 13, glans penis; 14, bulb of urethra; 15, cul-de-sac of bulb. *a*, Prostatic urethra; *b*, membranous urethra; *c*, spongy urethra (Testut).

gation of the fibers of the circular layer around the neck of the bladder and the beginning of the urethra, as the *sphincter vesicae*. The mucous coat or mucous membrane is covered with transitional epithelium, and contains racemose glands.

**Nerve-supply.**—The nerves supplying the bladder are, according to Langley and Anderson, derived from (1) the second to the fifth lumbar nerves, reaching the organ through the sympathetic chain, the inferior mesenteric ganglion, and the hypogastric nerves; (2) the second and third sacral spinal nerves. Stimulation of the

first group causes feeble, and of the second strong, contraction of the bladder.

**Function of the Bladder.**—The bladder acts as a reservoir for the urine until such time as it is passed in the act of *urination* or *micturition*. The urine is retained within the bladder by the tonic contraction of the sphincter vesicæ in the same manner as feces are retained in the rectum by the sphincter ani. The pressure of the urine when the bladder is full is equal to only 1 cm. of mercury, while it takes a pressure of at least 3 cm. to overcome the elasticity of the sphincter. When the bladder is about to be emptied, as the result of an inhibitory impulse, the sphincter vesicæ becomes relaxed. At the same time the muscular coat of the bladder and the abdominal muscles contract, and the urine begins to flow. The pressure which is thus exerted equals 10 cm. of mercury. Although the starting of the act is voluntary, when once it has begun it continues under the influence of the vesicospinal center situated in the lumbar part of the cord until the bladder is empty.

Up to a certain point the brain is able to inhibit the center and postpone the evacuation of the bladder, but after a time, if too long delayed, the resistance of the sphincter is overcome and urine will flow. It is more difficult to stop the act after it has once begun than to delay its beginning, for the urine, flowing over the mucous membrane of the urethra, stimulates the vesicospinal center, and the efferent impulses to the contracting muscles are increased.

If the mucous membrane of the bladder is inflamed, as in cystitis, the stimulation of the center may be so great as to prevent the brain from inhibiting the evacuation, and this may occur when only a small quantity of urine is accumulated. Or it may happen that the spinal cord is injured or diseased in the upper or middle portion, and thus all sensation caused by a full bladder may be abolished. Under these circumstances the bladder, when full, will be emptied by the reflex action of the vesicospinal center. Or, again, if the lesion of the cord is such as to disorganize this center, then there will be no reflex action of the cord, and the elasticity of the tissues about the neck of the bladder will keep the urine in that viscus until the elasticity is overcome by the distention, when the urine will flow in drops as fast as it comes from the kidneys; but the bladder will not empty itself. Inexperienced persons are often deceived by this dribbling of the urine, thinking that its discharge is evidence that the bladder is performing its duty, while the fact is that it is evidence of paralysis and retention.

**Urethra** (Fig. 244).—This canal extends from the neck of the bladder to the *meatus urinarius*, and in the male is about 20.4 cm. and in the female about 3.7 cm. in length. It is lined with

mucous membrane, in which are mucous glands, *glands of Littre*, and opening into it in the male are two compound racemose glands, *Cowper's glands*. In the female urethra the epithelium is stratified. In the male urethra it is stratified near the meatus, transitional in the prostatic portion, and elsewhere columnar.

## THE URINE.

**Quantity.**—The amount of urine voided by an adult in twenty-four hours is about 1500 c.c.; although it may vary within normal limits from 1200 c.c. to 1700 c.c. In health the increased drinking of fluids and lessened formation of the perspiration will increase the amount of urine excreted, while the excretion will be diminished if the quantity of liquids drank is lessened or if the perspiratory glands are more active. It is a matter of common observation that in summer the urinary flow is less than it is in winter.

**Color.**—The color is ordinarily yellow, though it may be, even in health, almost colorless or reddish brown. The urinary pigments are urochrome, urobilin, uroerythrin, and hematoporphyrin.

**Urochrome.**—This is the essential pigment to which the yellow color is due. It has been demonstrated that when alcoholic solutions of pure urochrome are treated with aldehyd a reducing action is produced on the pigment and urobilin is produced. This would indicate that urochrome is an oxidation-product of urobilin.

**Urobilin.**—This is the same as stercobilin of the feces, and is probably formed from the bilirubin of the bile. Urobilin exists in small amount in the urine, and principally in the form of a *chromogen*, to which the name *urobilinogen* has been given. Urobilin and hydrobilirubin are regarded by some as identical. Hopkins states that the origin of urinary bilirubin is probably threefold—from absorption of the ready-formed pigment in the bowel; from direct production in the liver; and from reduction of the blood-pigment in the organ, independently of hepatic agency.

**Uroerythrin.**—This coloring-matter is that which gives the characteristic color to the pinkish deposits of urates. It exists in small amount, but it is always present in normal urine.

**Hematoporphyrin.**—Although normally present in but small amount, this substance may exist pathologically in considerable quantity.

**Reaction.**—The reaction of the mixed urine passed in twenty-four hours is acid to litmus, due to the presence of sodium dihydrogen phosphate,  $\text{NaH}_2\text{PO}_4$ , or, as it is more commonly called, acid sodium phosphate.

The acidity of the urine is subject to considerable variation. It is increased after exercise and after the consumption of animal

food ; it is decreased after the ingestion of vegetable food, because this contains compounds of organic acids which by oxidation form carbonates, and these latter may be so plentiful as to make the urine alkaline.

The *alkaline tide* is a term applied to the condition in which during the period when hydrochloric acid is being set free as a constituent of the gastric juice the urine, through the elimination from the blood of the bases, becomes less acid and sometimes even alkaline.

There is also a difference in the degree of acidity of the urine at different times of the day, without regard to the food taken.

**Specific Gravity.**—This varies from 1015 to 1025, being lower when the quantity of urine is increased, and higher when it is diminished. It may, in extreme cases, as after the drinking of large quantities of fluid, be as low as 1005. In diseased conditions, as in diabetes mellitus, the quantity is greatly increased and this is accompanied by a high specific gravity.

**Composition.**—In the following table are given two analyses by Bunge of the twenty-four hours' mixed urine of a young man : The "meat diet" consisted of beef with a little salt and spring-water ; the "bread diet" consisted of bread, butter, and water :

	Meat diet.	Bread diet.
Total quantity in twenty-four hours .	1672 c.c.	1920 c.c.
Urea . . . . .	67.2 grams	20.8 grams
Creatinin . . . . .	2.168 "	0.961 "
Uric acid . . . . .	1.398 "	9.258 "
Sulphuric acid (total) . . . . .	4.674 "	1.265 "
Phosphoric acid . . . . .	3.437 "	1.658 "
Lime . . . . .	0.328 "	0.339 "
Magnesia . . . . .	0.294 "	0.139 "
Potash . . . . .	3.308 "	1.314 "
Soda . . . . .	3.391 "	3.923 "
Chlorin . . . . .	3.817 "	4.996 "

The urine of an adult living upon an ordinary mixed diet and amounting in the twenty-four hours to 1500 c.c. would contain approximately 1440 c.c. of water and 60 grams of solids, of which 35 grams would be urea.

**Urea,  $\text{CO}(\text{NH}_2)_2$ .**—Chemically this substance is an amid of carbonic acid, and is also described under the name *carbamid*. It is isomeric with ammonium cyanate,  $(\text{NH}_4)\text{CNO}$ , and was prepared therefrom by Wöhler in 1828. It crystallizes in the form of colorless needles or rhombic prisms ; is soluble in water and alcohol, but is insoluble in ether and chloroform.

With nitric acid, urea becomes *urea nitrate*,  $\text{CO}(\text{NH}_2)_2\text{NO}_3\text{OH}$ , which forms in its crystallization rhombic tables ; the angles of these are usually cut off, making six-sided crystals, which frequently overlap one another. The formation of these crystals is used as a test for urea.

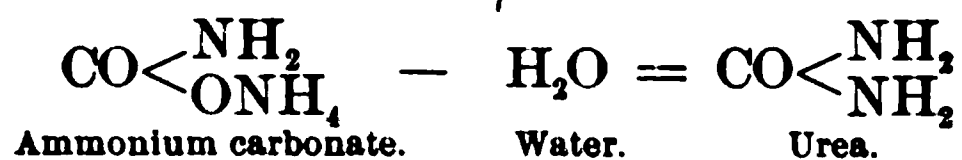
With oxalic acid urea forms *urea oxalate*,  $\text{CO}(\text{NH}_2)_2(\text{COOH})_2$  which crystallizes as short rhombic prisms.

Urea is converted into ammonium carbonate by the action of the ferment *Micrococcus ureæ*; this change which takes place in urine declares itself by the ammoniacal odor which is developed. It is represented by the following equation:



Urea is the end-product of the proteid metabolism of the body and of the albuminoids of the food. When a meal containing considerable proteids has been ingested, and the urea determined, the amount will be at a maximum at the third or fourth hour; this is supposed to indicate the absorption of peptones from the stomach. A second maximum occurs at the sixth or seventh hour, and this is attributed to the absorption of peptones from the intestine.

*Formation of Urea.*—Urea exists in the blood when that fluid reaches the kidney, and the function of this organ is, so far as urea is concerned, simply to eliminate it. Without recounting the experimental evidence, which is ample and satisfactory, it is enough to say that urea is formed by the cells of the liver. The most satisfactory explanation of the manner of this formation is that given by Drechsel, and is substantially as follows: Proteids undergo hydrolytic cleavage, and leucin, tyrosin, aspartic acid, and other amido-bodies are formed: these undergo oxidation, forming  $\text{NH}_3$ ,  $\text{CO}_2$ , and  $\text{H}_2\text{O}$ ;  $\text{NH}_3$  and  $\text{CO}_2$  unite to form ammonium carbonate,  $\text{CO} < \begin{smallmatrix} \text{NH}_2 \\ \text{ONH}_4 \end{smallmatrix}$ , which, by the loss of a molecule of water, brought about by the liver-cells, becomes urea:



Drechsel's view is that this is accomplished in two stages: First, two atoms of hydrogen are removed, and then one atom of oxygen.

A series of experiments by various physiologists have demonstrated that when the liver is removed from dogs, although this operation is ultimately fatal, carbonates appear in the urine and there is a diminished amount of urea. That any urea is found demonstrates that the liver is not its only source; but where else it is formed is not known.

**Uric Acid** ( $\text{C}_5\text{N}_4\text{H}_4\text{O}_3$ ).—The amount of this substance in human urine is very small, being on an average about 0.8 gram, but it is the principal nitrogenous constituent of the urine of birds and

reptiles, and is the end-product of their proteid metabolism, as urea is that of mammals. When pure it crystallizes in the form of small rhombic crystals, which vary much in shape when deposited from the urine, and this is said to depend upon the nature of the pigment with which they are associated.

Uric acid is soluble in cold water to the extent of but 1 part in 15,000; 1 liter of boiling water will dissolve  $\frac{1}{2}$  gram. It is soluble in sulphuric acid, but insoluble in ether and alcohol.

The presence of uric acid is recognized by means of the murexid-test, or, as it is sometimes called, Weidel's reaction. It is applied as follows, the method being that recommended by Hopkins, which he regards as the most delicate method of applying it: If a small quantity of uric acid is placed upon a watch-glass, a little strong nitric acid or a few drops of bromin-water added, and the whole dried upon the water-bath, an orange-red residue is obtained, which, if touched with a drop of ammonia, yields a fine purple color. If a minute quantity of sodium hydrate solution is subsequently added, the purple color changes to blue, while on warming the alkaline solution all color is discharged. The water-bath should always be used for evaporation in applying this test, and if the watch-glass is allowed to remain in the bath for a considerable time after evaporation is complete, a red color will develop without further treatment, and the residue will dissolve to a purple solution in distilled water. It is on account of this purple color that the test receives its name. From the genus *Murex* were obtained various colors; two of these mollusks, *Murex brandaris* and *Murex trunculus*, yielded a secretion which, when exposed to the air, became purple. The celebrated Tyrian purple was obtained from these gastropods.

Uric acid is dibasic, and there are formed by it three forms of salts: *Neutral urates*, which do not occur in the urine; acid urates or *biurates*; and *quadriurates*.

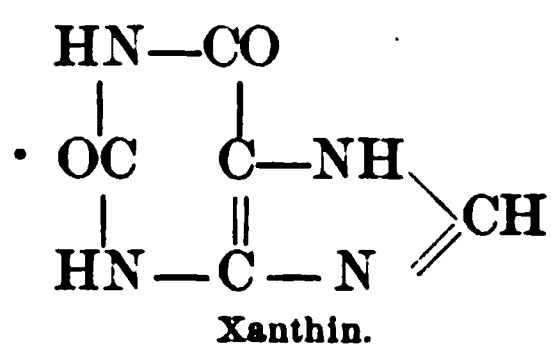
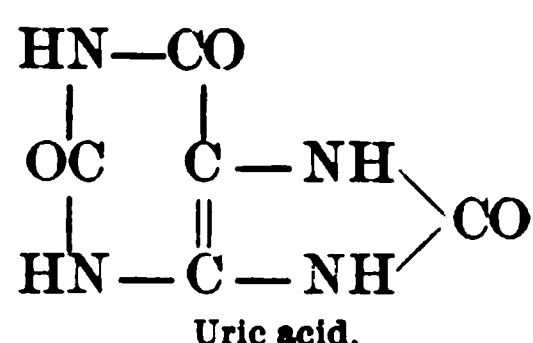
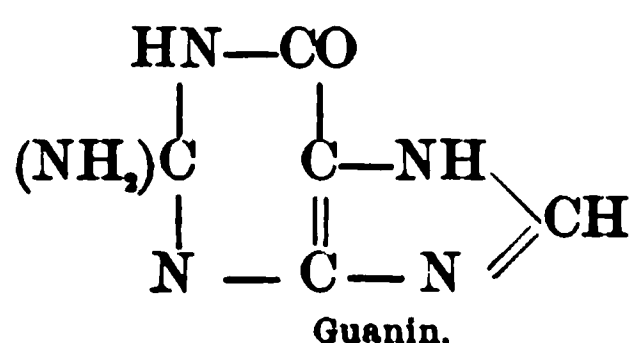
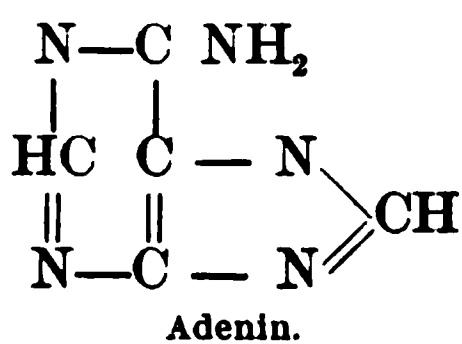
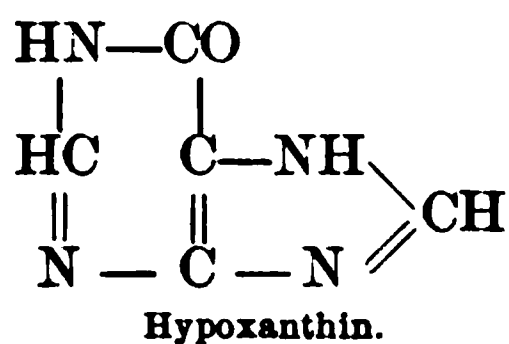
As already stated, uric acid does not exist free in urine—*i. e.*, in recently passed urine; though after standing and being cooled uric acid is deposited as such. The deposit of uric acid which ordinarily occurs is that known as *brick-dust* or *lateritious deposit*, and consists of urates in an amorphous condition. Although these are usually regarded as biurates, Roberts considers them to be quadriurates.

*Sources of Uric Acid.*—In a paper concerning the sources of uric acid, published in the *Brooklyn Medical Journal* under the title "The Genesis of Uric Acid," Chittenden prefaces his consideration of the subject by emphasizing two vital points:

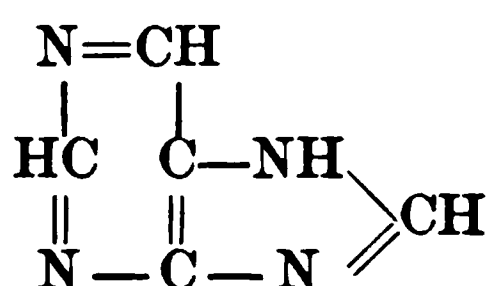
"First, the close chemical relationship of the purin bases, viz., adenin, hypoxanthin, guanin, xanthin, and the methyl xanthins, theobromin, caffenin, etc., together with uric acid, which is likewise



a purin body. The intimate chemical relationship of these bodies is indicated by the following structural formulæ :



“Purin, as has been shown by E. Fischer, has the formula :



“The purin bases and uric acid are derived from purin by simple substitution of the various hydrogen atoms by hydroxyl, amid, or alkyl groups, as is plainly evident from comparison of the different formulæ.

“Secondly, it must be noted that all true nucleins on decomposition by chemical means yield more or less of the above purin bases, as was first pointed out by Kossel. This means that all nucleins contain in their molecules some purin bases—*i. e.*, in a state of combination, from which combination they can be split off by appropriate means either in the body or by chemical methods outside of the body. Further, as these nuclein or purin bases stand in such close relationship to cell-nuclei, it is easy to see how the quantity of these substances may be largely increased whenever from any cause the number of nucleated cells is increased in any part of the body. Thus, while normal blood yields only traces of purin bases, in leukemia the amount of nuclein bases may be increased to over 0.1 per cent.”



Prof. Chittenden concludes his admirable paper in the following language :

“In man uric acid has a twofold origin ; one portion, coming from the breaking down of nuclein-containing tissues or cell-elements of the man's own body, and hence is of endogenous origin, while the other portion—usually the larger—is of exogenous origin, coming from the transformation of free and combined purin compounds present in the food. The uric acid of endogenous origin is essentially constant in amount for the same individual under all conditions of diet, but is subject to slight variation in connection with alterations in the activity of the tissues. Changed conditions embodying increased katabolism of the tissue-elements, increased breaking down of cells and cell-nuclei, might naturally be expected to cause slight alteration in the amount of endogenous uric acid, but analytic results at present do not justify belief in any profound changes in the uric acid output due to this cause. The amount of endogenous uric acid is, therefore, a physiologic constant for a given individual, and, as might be expected, decided variations are to be found in the value of this constant for different individuals. In other words, personal idiosyncrasy, constitutional differences, etc., may manifest themselves in the amount of endogenous uric acid produced. Such a condition of things is by no means strange or out of harmony with physiologic laws. There is a personality in every man, internal as well as external, and the individual constancy in endogenous uric acid production is merely another illustration of the general truth of this law. Individual functional peculiarities are as liable to existence as personal peculiarities of form and structure.

“The amount of exogenous uric acid produced in the body is dependent mainly upon two factors, viz., the quantity and character of the nucleins contained in the ingested food, and the quantity and character of the free purin bases present in the food. The nucleins owe their influence solely to the combined purin bases they contain, and since nucleins from different glands and tissues differ both in the amount and character of the purin bases present in their molecules, it follows naturally that the individual nuclein-containing foods have different values as sources of exogenous uric acid. Further, since all nucleins are somewhat slowly attacked by the digestive fluids, it follows that the uric acid coming from this source does not appear at once in the urine, but is found some hours after digestion has been under way. The free purin bases, on the other hand, such as are contained in meats, meat-juice, meat-extracts and soups, coffee, cocoa, etc., lead to a quicker output of uric acid, owing to their ready solubility and availability. Differences in the extent of this form of exogenous uric acid production, however, are traceable to differences in the *nature* of the free purin bases ; adenin, hypoxanthin, and guanin,

for example, showing distinct differences in the extent to which they are individually converted into uric acid in the body.

“Finally, we see that there is no causal relationship whatever between the daily urea and uric acid output. They come from totally different lines of metabolism; they stand for totally distinct chemico-physiologic processes; and hence any attempt to emphasize the so-called ratio of urea to uric acid in the urine is misleading, and shows, furthermore, a lack of understanding of the true genesis of these two excretory products. Between uric acid and ordinary proteid metabolism there is no connection whatever. With a purely non-nitrogenous diet, on the one hand, and a diet rich in eggs, milk, and cheese, on the other, with perhaps a maximum amount of contained proteid, the output of uric acid remains practically unchanged. The genesis of uric acid is to be found solely in metabolism of the tissue nucleins (endogenous) and in the transformation of the nucleins and free purin bases of the ingested foods (exogenous).”

In discussing this subject, J. Walker Hall, in his book, “The Purin Bodies of Food stuffs,” etc., says: “As ‘endogenous’ purins are practically waste-products on their way to excretion, so when they become ‘exogenous’ to another organism, they have little nutritive value and demand early and rapid elimination. This is generally effected by the oxidation of the oxy-purins, hypoxanthin and xanthin, to uric acid, and then the purin ring or chain in the uric acid is in the liver partially split off and a portion of the uric acid excreted as urea.” It would appear from this statement that there is a certain relationship between uric acid and urea, but this is quite different from the old idea that a certain definite ratio exists between the output of urea and uric acid on the assumption that both come from the ordinary proteid katabolism.

There is evidence looking toward the synthetic production of uric acid in the liver, but this is not yet proven. The influence of alcohol and alcoholic fluids in the excretion of uric acid is discussed elsewhere (p. 161).

**Xanthin Bases.**—The urine contains besides xanthin, the following members of this group: *Heteroxanthin*, *paraxanthin*, *hypoxanthin*, *guanin*, *adenin*, and *carnin*. They are related to uric acid, as is shown by the formulæ given on page 435, and these bases and uric acid are called by Krüger and Wulff *alloxuric substances*, because of their relation to alloxan and urea. The amount of the xanthin bases daily excreted in the urine is about 0.1 gram. They are increased after taking green vegetables and on a diet containing much nucleins, and also in some form of leukemia.

**Hippuric Acid** ( $C_9H_9NO_3$ ).—Although present in herbivora in considerable amount—2 per cent. in cattle—hippuric acid occurs in human urine on an ordinary diet to the amount of but about

liem, being increased three or four times this enter largely into the diet.

his substance exists in human urine under a mixed t of about 1 gram in the twenty-four hours. Its is the creatin contained in the meat ingested, as the following equation :



that some of the creatinin in the urine may come of the muscular tissue of the body, although lished.

the urine is a minute quantity of a *nucleoproteid* ning the urinary passages. This may be present ntity to react to *Heller's test*, which consists in o flow down the side of a test-tube in which is d. The urine floats on the acid, and where the e ring of coagulated proteid forms. In *cystitis*, of the mucous membrane lining the bladder, the ucleoproteid may be increased, and this is precip- tic acid is added to the urine. The nucleo- ine is also increased in leukemia.

—Under some circumstances serum-albumin and re found in the urine, constituting *albuminuria*. always exist in minute quantities in health, but the cells of the passages along which the urine from the blood as it flows through the glomeruli, edly do in true albuminuria, which is a patho-

**d Albumosuria.**—These conditions are character- sence in the urine of peptones and albumoses, e have already seen that the products of digestion, aged in their passage through the gastric and by the cells into, probably, serum-albumin and certainly, they do not enter the blood as peptones. s much diseased, as in cancer of the stomach, d albumoses or proteoses may not be changed, ie blood in these forms and appear in the urine, by the kidneys. It is probably in the form of

albumoses or proteoses rather than peptones that this elimination takes place. This condition of peptonuria may occur in connec- tion with abscesses or collections of pus, the pus-cells having broken down, and peptone being one of the products which is taken up by the blood and carried to the kidneys, where it is eliminated.

**Aromatic Substances.**—Hippuric acid or benzamido-acetic acid belongs to the aromatic series, by reason of its containing the benzene nucleus. Besides this, there are other aromatic substances which come from the food and also from the proteids of the tissues. Among these are *phenol*, *kresol*, *pyrocatechin*, sometimes *inosit*, and various *carboxyacids*. *Indoxyl*, which is produced by the oxidation of the indol that is absorbed from the intestine, and *skatoxyl*, produced in the same manner from skatol, also occur in urine.

**Dextrose.**—Ordinary urine contains dextrose to the amount of from 0.08 to 0.18 gram per diem. The presence of dextrose in normal urine has been and still is denied, but the most recent investigations seem to leave no doubt upon this much mooted question.

We have seen that *alimentary glycosuria* may occur when an excessive amount of sugar is ingested. In *diabetes mellitus* the quantity of dextrose in the urine may be very great, 500 or 600 grams being excreted in a single day. The methods of recognizing the presence of dextrose have been previously referred to (p. 87).

**Lactose.**—The presence of this variety of sugar in the urine constitutes *lactosuria*, and this condition of the nursing mother's urine is quite constant. Lactose is formed by the mammary gland, absorbed by the blood, and eliminated by the kidneys. It must be inverted before it can be changed into glycogen; this inversion takes place when lactose is ingested with the food, but when absorbed by the blood from the mammary gland, it does not occur. Under these circumstances lactose enters the blood directly as lactose and is excreted in the urine.

Lactosuria is a condition which has escaped general recognition, and in speaking of it Hopkins says: "If the urine exhibits the following characters, the presence of lactose is established almost without the possibility of doubt: It should reduce copper and bismuth solution; but with the fermentation-test, it should give negative results for the first twenty-four hours of the experiment, and it should give no definite crystalline precipitate with the phenylhydrazin test when this is directly applied. On the other hand, after boiling with 5 per cent. sulphuric acid for a short time the urine should, if first neutralized with ammonia, give the phenylhydrazin test readily: crystals of dextrosazon should be thus obtained, and with proper precautions galactosazon crystals may also be distinguished. Although the lactose is converted by the mineral acid into dextrose and galactose, fermentation is not always to be obtained after treatment, as the large amount of sulphate which is present after neutralizing the acid interferes with the growth of the yeast. If the reducing power of the urine is estimated, this should be found increased after boiling with mineral acid, but unaffected by boiling with citric acid."

**Inorganic Constituents.**—The inorganic ingredients which occur in the urine are mainly in the form of chlorids, phosphates, sulphates, and carbonates, combined with sodium, potassium, ammonium, calcium, and magnesium, and are excreted to the amount of about 25 grams per diem, of which about 15 grams are sodium chlorid, derived almost exclusively from that taken in with the food.

The inorganic constituents eliminated in the urine come from (1) the inorganic constituents of the food, and (2) from the destructive metabolism of the body-tissues. In the first group are the chlorids and the principal part of the phosphates; in the second, the sulphates, which occur in but small quantities in the food, and a small part of the phosphates.

**Chlorids.**—Although the urine contains some potassium chlorid, it is mainly by sodium chlorid that these salts are represented. Inasmuch as its quantity in the urine depends upon that taken in with the food, this is subject to considerable variation. In disease any process which results in taking sodium chlorid from the blood will correspondingly diminish its excretion in the urine; this occurs in the exudations which accompany pneumonia and pleurisy. When these are absorbed, the chlorid of sodium again enters the blood and the quantity in the urine is increased.

**Phosphates.**—In the metabolism of the tissues of the body some of the phosphorus contained in nuclein, lecithin, and protagon is oxidized, producing phosphoric acid, which in the form of phosphates is excreted in the urine; the amount of this is, however, small. Most of these salts which occur in the urine are derived from the food; hence their quantity is increased with an animal diet, while with a vegetable diet it is diminished. The phosphates of plants are not absorbed by the animal, because of their insolubility, hence in the urine of herbivorous animals these salts are deficient. The amount of phosphoric acid daily excreted in human urine is about 3.5 grams.

The phosphates exist in two forms: (1) Alkaline and (2) earthy. The *alkaline phosphates* are those of sodium and potassium; while the *earthy phosphates* are those of calcium and magnesium.

Sodium dihydrogen phosphate, also called acid sodium phosphate,  $\text{NaH}_2\text{PO}_4$ , is the principal factor in giving urine its *acid* reaction, although associated with it in this office is calcium dihydrogen phosphate,  $\text{Ca}(\text{H}_2\text{PO}_4)_2$ . When the reaction of the urine is *neutral* there are also present disodium hydrogen phosphate,  $\text{Na}_2\text{HPO}_4$ , calcium hydrogen phosphate,  $\text{CaHPO}_4$ , and magnesium hydrogen phosphate,  $\text{MgHPO}_4$ . When the urine is *alkaline* these may also be present, accompanied by the *normal phosphates*,  $\text{Na}_3\text{PO}_4$ ,  $\text{Ca}_3(\text{PO}_4)_2$ ,  $\text{Mg}_3(\text{PO}_4)_2$ , or these latter may replace the former.

When the urine becomes alkaline, whether as a result of the decomposition of urea and the formation of ammonium carbonate or by the addition of ammonia, the earthy phosphates are precipitated. From alkaline decomposing urine, crystals of *ammonio-magnesium phosphate*, *magnesium ammonium phosphate*, or *triple phosphates*, by all of which names they are known, are deposited. The chemical formula of this deposit is  $\text{NH}_4\text{MgPO}_4 + 6\text{H}_2\text{O}$ . It forms *coffin-lid* crystals or star-shaped figures.

Urine that is slightly acid deposits star-shaped masses of prisms of calcium phosphate, called from the form of the crystals *stellar phosphates*.

**Sulphates.**—Only a small quantity of the sulphates comes from the food, most of it being the result of the metabolism of the proteids of the body, into which sulphur enters as a component part. These salts occur in the urine in two forms: (1) *Inorganic sulphates* and (2) *etheral or conjugated sulphates*. The total amount of sulphates daily excreted in the urine varies from 1.5 grams to 3 grams, of which about one-tenth is in the form of the conjugated sulphates. The conjugated sulphates consist of radicles derived from the aromatic substances present in the urine, joined with sulphuric acid, from which fact they derive their name. Among the most important of the etheral sulphates are phenol-potassium sulphate and indoxyl-potassium sulphate: besides these are kresol-potassium sulphate, skatoxyl-potassium sulphate, etc. These salts are increased when the putrefaction of proteid substances in the intestines is increased. Whenever, therefore, the amount of sulphuric acid in the urine is increased, it may be due to an increased amount of sulphates in the food or drink, or to increased putrefaction in the intestines.

There is, according to Hopkins, also some sulphur in the urine in the form of *neutral sulphur*, as contradistinguished from the "acid sulphur" of the sulphates. It is in a less oxidized form than the sulphates, but what the compounds are is not known. It is said that one-fifth of the total sulphur of the urine is in this form. Some of this may come from the taurin of the bile.

**Carbonates.**—When the urine is alkaline, sodium, calcium, magnesium, and ammonium carbonates are present. These are especially abundant after a vegetable diet, for the reason that the malates, tartrates, and citrates contained in such food are converted into carbonates, which are eliminated by the kidneys. Carbonic acid also exists in acid urines, as much as 50 c.c. per liter having been found present.



IRRITABILITY; CONTRACTILITY; ELECTRIC PHENOMENA  
OF MUSCLE.

**Irritability** is the property possessed by living tissues by virtue of which they respond to certain external agents called *irritants* or *stimuli*. A *stimulus*, therefore, is an agent which is capable of producing in living tissues certain changes by which is manifested the fact that they are living, the character of these changes varying according to the tissue which is the subject of the stimulation. When this change consists in one of *form*, it is **contractility**. Thus, simple protoplasm, as in the ameba, will, when touched, draw in the processes or pseudopodia which it had previously put out (p. 24). Here the touch was the stimulus which caused the irritability of the protoplasm to manifest itself by contraction. Or if a muscle is stimulated by an electric current, it shortens, thus manifesting its irritability by contraction. In both these instances the response to the stimulus is a change of form. If, however, a current of electricity is passed through a nerve, the closest inspection fails to reveal any change in the nerve itself: it neither moves its position nor in any wise changes its form; and yet a nerve is irritable—*i. e.*, has the property of responding to a stimulus. If it is a motor nerve—that is, one distributed to a muscle—when it is stimulated its contractility will be manifested by a contraction of that muscle; or if it is a secretory nerve—that is, one supplying a gland—its irritability will be manifested by an increased activity of the gland.

It is not, however, essential that in order to manifest contractility muscles should be stimulated through the motor nerve which is distributed to them, as a stimulus applied directly to the muscle itself will cause the muscle to contract. That muscular tissue possesses irritability independently of the nerves distributed to it was for a long time in dispute, but is now conceded by all authorities, the proof which was furnished by Claude Bernard's experiment being incontrovertible. This consists in destroying the brain of a frog by pithing it—*i. e.*, passing a blunt needle into the cranial cavity and moving it about. This destroys consciousness; but the circulation of blood continues. The left sciatic nerve is then dissected out, and a ligature passed beneath it, and all the tissues of the thigh excepting the nerve are tightly tied: thus is cut off the blood-supply to all the parts below the ligature; but the nerve is at the same time uninjured. Under the skin of the back a few drops of a 2 per cent. solution of curare are then injected. If after some time, about half an hour, the nerve is stimulated, there will be no contraction of the muscles supplied by it; but if the stimulus is applied directly to the muscles, they will respond. Experiment shows that curare poisons the motor end-plates, so that although the nerve carries the current to this end-organ, its influence can

pass no farther. It has also been demonstrated that muscular tissue in which there are no nerves will respond to stimuli; so that of the existence of independent muscular irritability there is no doubt.

**Stimuli.**—Stimuli may be general or special.

**General Stimuli.**—These are electrical, chemical, mechanical, and thermic. A current of electricity will stimulate a muscle or a nerve; certain chemicals will also stimulate them; but there are some of these agents which will stimulate a nerve and not a muscle; still others will stimulate a muscle and produce no effect upon a nerve. A blow will stimulate either a muscle or a nerve, and is an instance of a mechanic stimulus, and heat or cold suddenly applied will cause a response in either.

**Special stimuli** are those whose influence is restricted to a single nervous apparatus; thus light affects only the retina; sound-waves, only the organ of Corti; and the senses of smell and taste require special stimuli to excite them.

The manner in which stimuli act is not thoroughly understood. It is compared by Sir William Gowers to the blow that explodes dynamite or the match which ignites a mass of gunpowder.

Although any of the stimuli above mentioned may be used to demonstrate irritability and to study it, still it has been found that the most reliable and satisfactory results are obtained when an

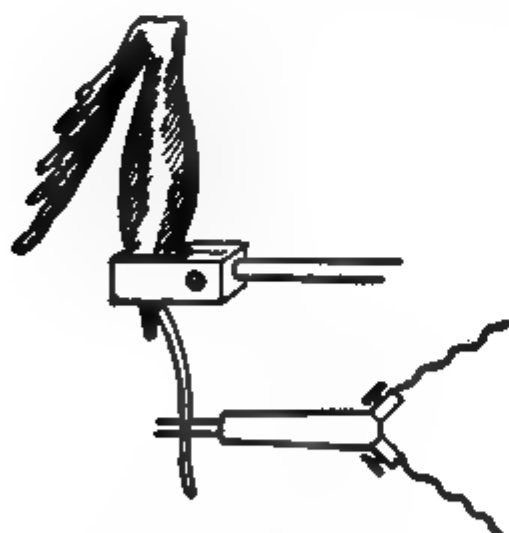


FIG. 245.—Experiment for determining the irritability of nerves.

FIG. 246.—Daniell cell.

electric stimulus is used, as this is more readily controlled and measured than any of the other varieties of stimuli, and for this purpose a *muscle-nerve preparation* is made (Fig. 245). It consists of the gastrocnemius muscle of a frog with the sciatic nerve attached, a portion of the bone being also removed by which it may be clamped in an appropriate holder. The electric current may be applied to the muscle directly, constituting *direct stimulation*, or to the nerve through which it passes to the muscle, *indirect*



*stimulation*; the result in either case being a shortening or contraction of the muscle, which may be made manifest by some device attached to the tendon of the muscle.

*Battery.*—For the generation of the current the *Daniell cell* (Fig. 246) is the one best adapted and most commonly employed. In it polarization is prevented and its constancy is very great. Polarization consists in a diminution in the intensity of the current, caused by a film of hydrogen which forms on the copper plate. The Daniell cell consists of a glass jar holding dilute sulphuric acid or a solution of copper sulphate, in which is a sheet of copper of a cylindric form. Within the latter is a porous jar containing a solution of zinc sulphate, within which is a zinc prism. To keep the solution of copper sulphate saturated, crystals of this salt are placed in a perforated pocket attached to the copper plate. The action of the sulphuric acid upon the zinc results in chemical changes by which a current of electricity is generated when the zinc and copper are metallically connected. The current within the cell flows from the zinc to the copper, while outside it flows from the copper to the zinc. The *zinc* is the *positive plate*, and the *copper* the *negative*: but the end of the wire which is connected with the copper is the *positive pole* or *anode*, and that connected with the zinc plate is the *negative pole* or *kathode*. When the unattached ends of these wires connecting the zinc and the copper are brought into contact with a nerve a current of electricity flows through the nerve, the direction being from the anode to the kathode. The wires are also termed *electrodes*, though this term is more commonly applied to the terminations of the wires attached to suitable holders. When

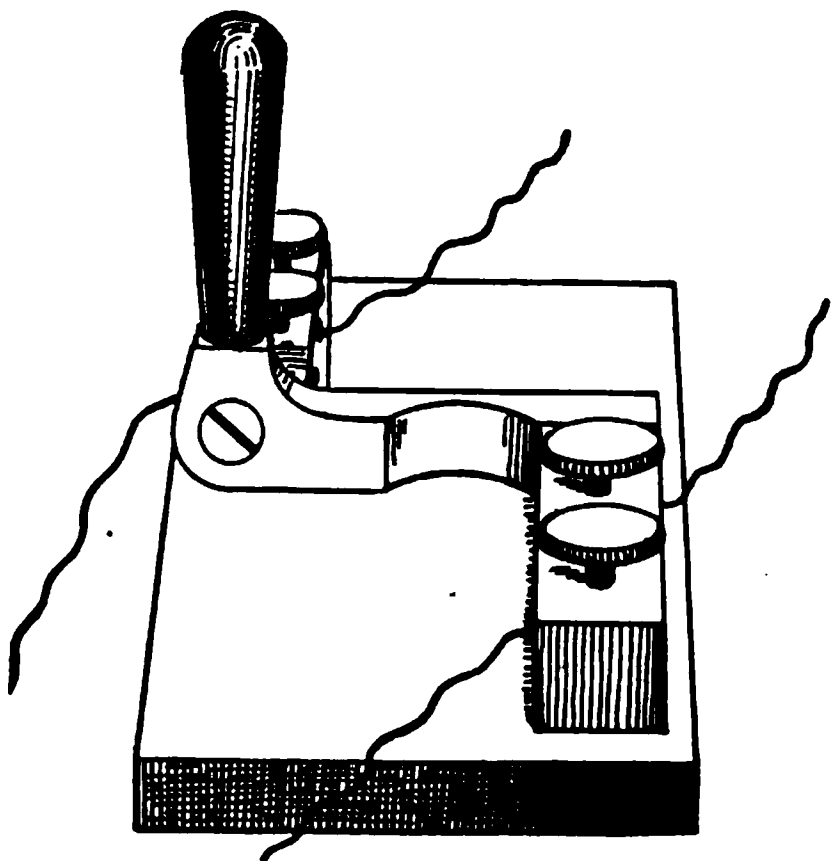


FIG. 247.—Electric key.

the electrodes are brought into communication through the intervening nerve the circuit is *closed*, and a contraction of the muscle occurs; when one of them, or both, is removed from the nerve the circuit is *broken*, and another contraction follows; or the same results will follow if the muscle is directly stimulated without the intervention of the nerve.

*Keys.*—A more convenient method of stimulating a nerve or muscle is by placing the one or the other upon the electrodes, which

are not connected directly, but through the intermediary of a key. When the key is open the circuit is broken, and when it is closed

the circuit is also closed and a current passes. The closing of the key is *make*; its opening, *break*; these being abbreviated expressions to imply that the circuit is closed or made, and open or broken.

*Du Bois-Reymond Key* (Fig. 247).—By this key the circuit

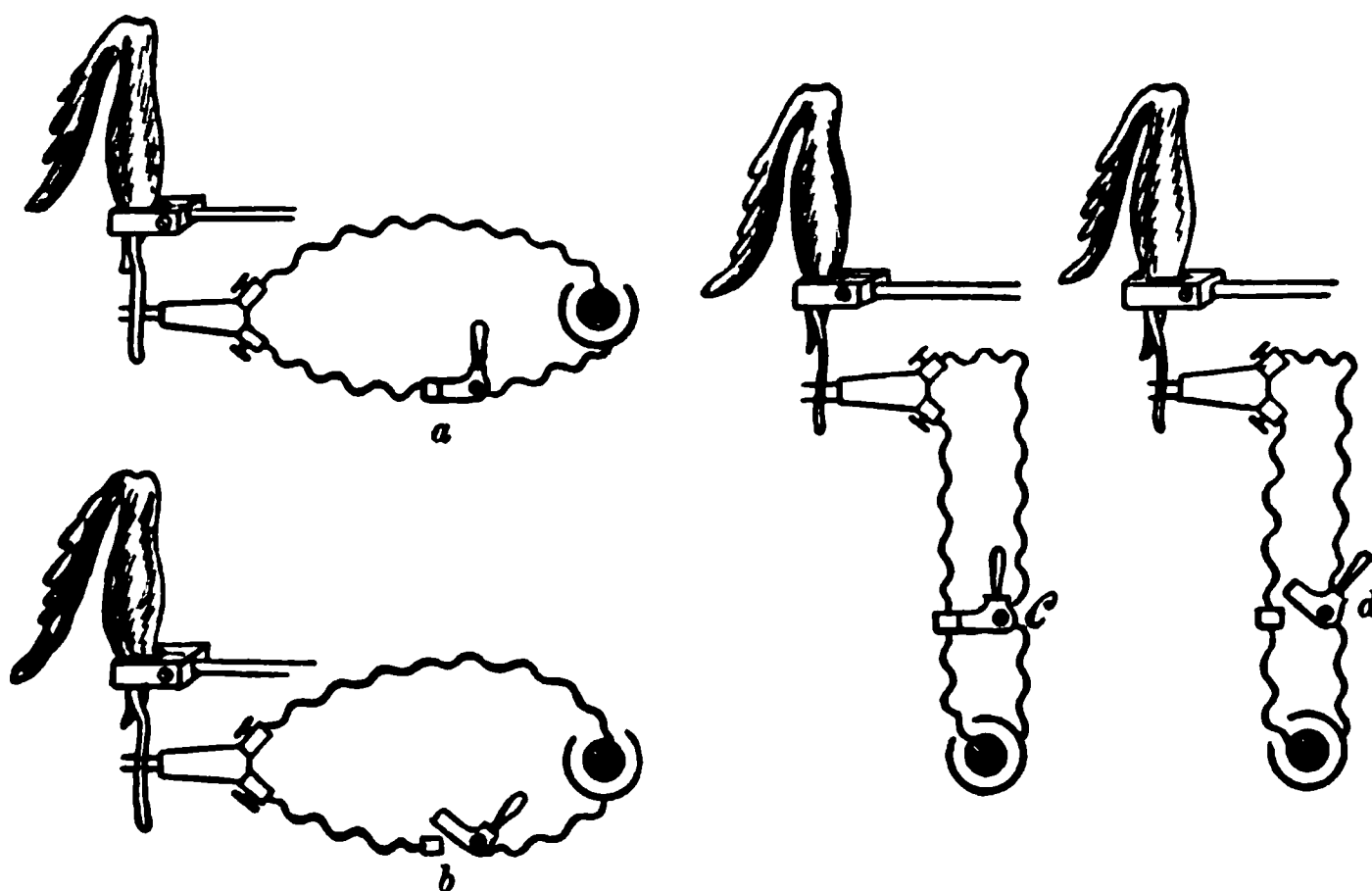


FIG. 248.—Electric circuiting.

may be either closed or the current *short-circuited*. In Fig. 248 these two methods of the use of the key are shown. At *a* the current is passing through the nerve because the key is closed, and at *b* it is not so passing, because the key is open. When used

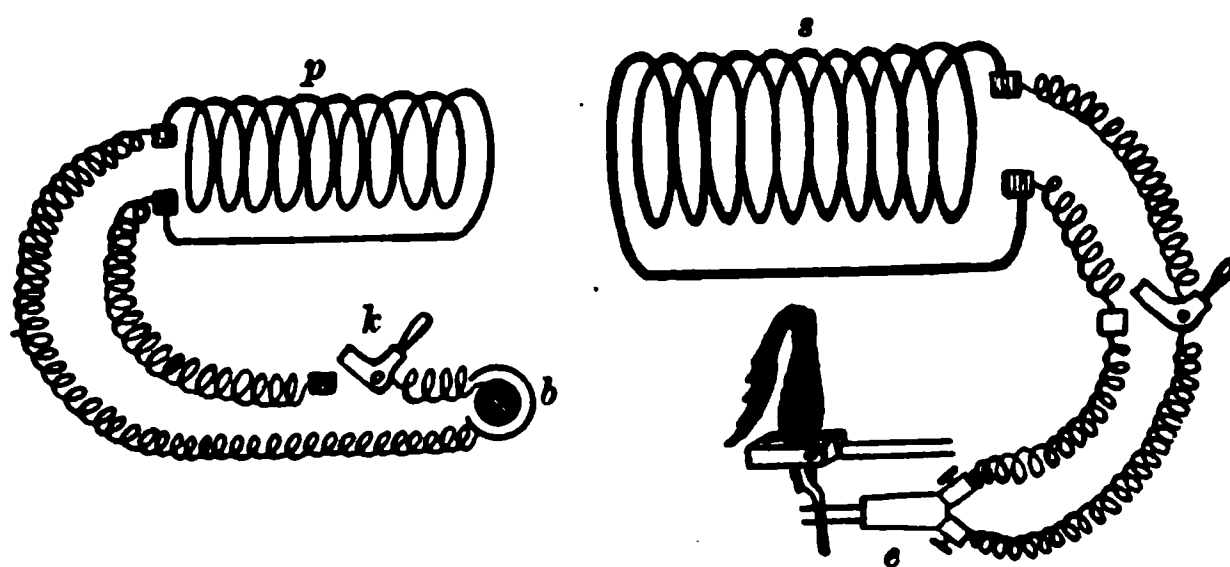


FIG. 249.—Schema of induction apparatus.

in the manner shown at *c* and *d* the battery is at all times connected with the electrodes which are in connection with the nerve, so that the current is at all times taking this path when the key is open at *d*; but when the key is closed, as at *c*, the key offering less resist-

ance than the nerve, the current takes the short path through the key, and none of it, or so little as not to be worth considering, passes through the nerve. It is at the make and break that muscular contractions occur, and then only; the contraction being stronger when the circuit is closed than when it is opened. It has been demonstrated that if a current is permitted to pass through a nerve, and gradually increased, and again gradually decreased, no contraction of the attached muscle occurs; the make and break must be sudden.

*Induced Current.*—This is a more powerful stimulus to the

FIG. 250.—Du Bois Reymond's inductorium: *B*, primary; *B'*, secondary coil; *H*, guides in which *B'* slides, with scale; *D*, electromagnet; *E*, vibrating spring; *i*, wire connecting wire of *D* to end of primary; *A*, *A'*, binding screws to which are attached the wires from battery; *A'* is connected with the wire of the electromagnet *D*, and through it and *i* with the primary.

nerves than the galvanic current produced in a voltaic cell, such as that of Daniell.

In Fig. 249, *b* represents a battery the current of which can be permitted to pass or not through the primary coil *p* by closing

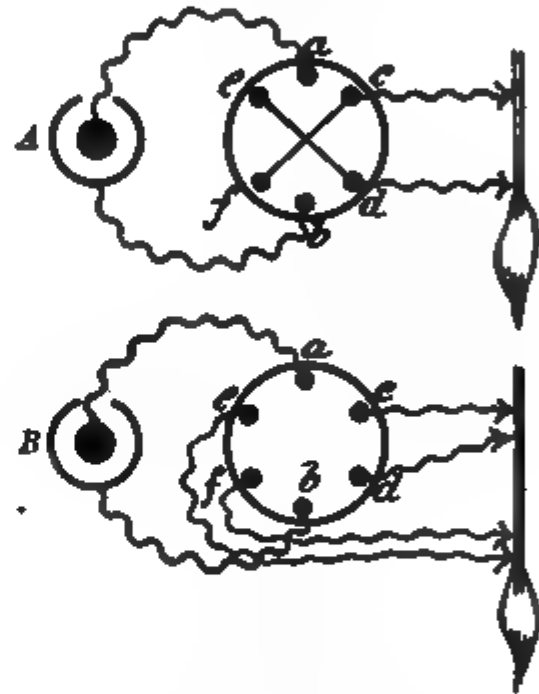
FIG. 251.—Unpolarizable electrode: *A*, hook-shaped; *B*, V-tubes; *C*, straight; *D*, clay in contact with tissue; *S*, saturated zinc sulphate solution; *Z*, amalgamated zinc wire (Stewart).

or opening the key *k*. If near this coil a secondary coil, *s*, is placed, with its electrodes connected with a muscle, at the moment the key *k* is closed in the primary circuit a current is in-

duced in the secondary coil, which is manifested by a contraction of the muscle. The effect upon the muscle is brief, and it returns to its former condition, and so long as the current is flowing no further change takes place in it; but the moment the primary current is broken the muscle again contracts, because of the production of another induced current. It will be recalled that with the direct battery current the closing of the circuit, or the *make*, produced the greater effect upon the muscle; in the induced current it is the *break* which produces the more powerful shock.

*Du Bois-Reymond's Inductorium* (Fig. 250).—This induction apparatus is the one most commonly used in physiologic laboratories.

To render the make and break shocks of the secondary coil



FIGS. 252, 253.—Pohl's mercury commutator.

more equal, Helmholtz connected one pole of the battery with *v* (Fig. 250), and the other with *A*, and *A* and *v* with a short and thick wire. On account of the wire between *v* and *A*, the primary current is never opened, but passes through the primary coil, and when the vibrating spring and *v* come into contact, the current is short-circuited.

*Non-polarizable Electrodes*.—When a muscle or other tissue is placed upon metal electrodes through which a current is passing, the electrodes become polarized as a result of the decomposition taking place in the tissue, and consequently currents are set up which materially interfere with a proper interpretation of the effects of the current from the battery or from the induced current, as the case may be. To avoid this, special forms of electrodes have been devised which are known as *unpolarizable* or *non-polarizable electrodes*. Fig. 251 shows such electrodes. Each one

consists of a glass tube, at one end of which is an opening; the lower part of this tube is filled with China clay, mixed with normal saline solution, which projects a little through the opening so that it may come into contact with the tissue to be investigated. The portion of the tube above the clay is filled with a saturated solution of zinc sulphate, into which dips an amalgamated zinc wire. When the experiment is of long duration the form represented by the middle figure in the illustration is best adapted; the U-shaped tube is filled with the zinc sulphate solu-

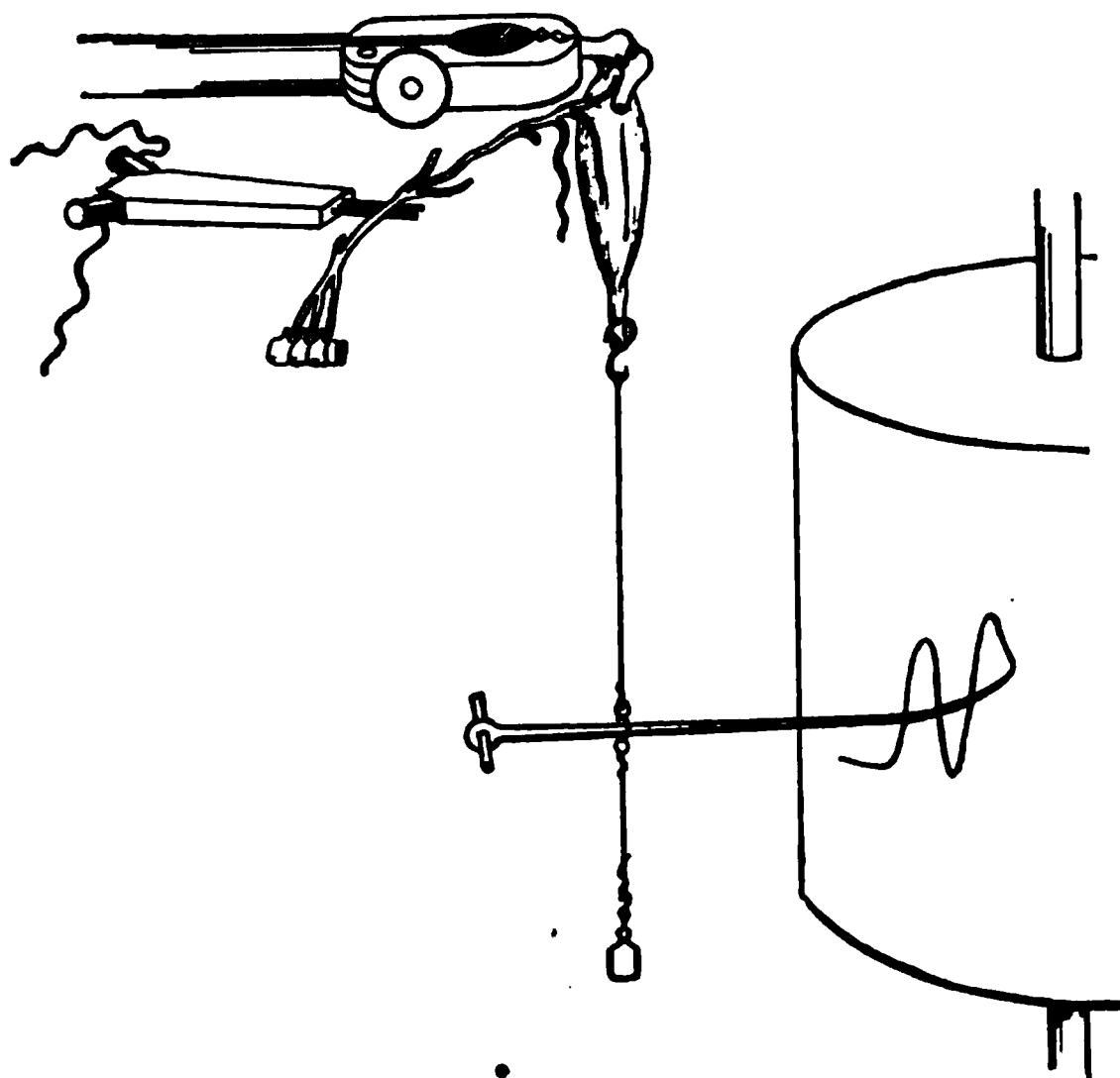


FIG. 254.—Method of recording muscular contraction (Lombard).

tion, and into one end dips the wire, and into the other a glass tube filled with clay, on which the tissue rests.

*Pohl's Commutator* (Fig. 252).—In order to reverse the direction of the current, Pohl's mercury commutator is used. This consists of a block of some insulating material, as paraffin or wood, with six cups containing mercury, each of which is connected to a binding-post. In Fig. 253, A, it will be seen that *a* and *b* are connected with the battery, *c* and *d* with the electrodes, and *e* and *f* with movable wires in such manner that *c* connects with *f* and *d* with *e*. Above the block is a bridge of some insulating material, glass or vulcanite, to which two semicircles of wire are attached, one of which is connected with a wire dipping into the cup *a*, and the other with a wire dipping into the cup *b*. This bridge can be rocked back and forth, so that if the ends dip into the cups *c* and *d*, *a* will be connected with *c*, and *b* with *d*; while

if they dip into *e* and *f*, *a* will be connected with *e*, and through the cross-wire with *d*, and *b* will be connected with *f*, and through the cross-wire with *c*. This arrangement permits the battery-current to pass by way of *a* and *e* down the nerve, and back to the battery by way of *d* and *b*; or from the battery through *a*, *e*, and *d*, and up the nerve and back to the battery by way of *c*, *f*, and *b*.

In Fig. 253, *B*, the cross-wires have been removed, and, as shown by the diagram, the current can be sent through *c* and *d* to one part of the nerve, or through *e* and *f* to another, by rocking the bridge back and forth.

*Myographs*.—In order properly to study the effects of the

FIG. 255.—Spring myograph: *A*, *B*, iron uprights, between which are stretched the guide-wires on which the travelling plate *a* runs; *k*, pieces of cork on the guides to check gradually the plate at the end of its excursion and prevent jarring; *b*, spring, the release of which shoots the plate along; *h*, trigger-key, which is opened by the pin *d* on the frame of the plate (Stewart).

induction shocks upon the nerves and muscles it is necessary to have some method of recording the movements of the muscles which these shocks produce. Such an instrument is the *myograph*. The nerve-muscle preparation has already been described. The tendon of the muscle is attached to a lever, and to this latter is attached a writing-point, which rests against a piece of paper wrapped around a revolving drum, the paper revolving with the drum. When the muscle contracts, it raises the lever and an upward line is made by the point on the paper; when the muscle relaxes, the lever falls and the point makes a descending line. Inasmuch as this drum is revolving all the time, these lines take the form of curves. Such a record is a *myogram* or *muscle-curve*, and may be preserved

for the purpose of study. Fig. 254 represents the method of recording muscular contraction.

Other forms of the myograph are the *spring myograph* (Fig. 255) and the *pendulum myograph* (Fig. 256).

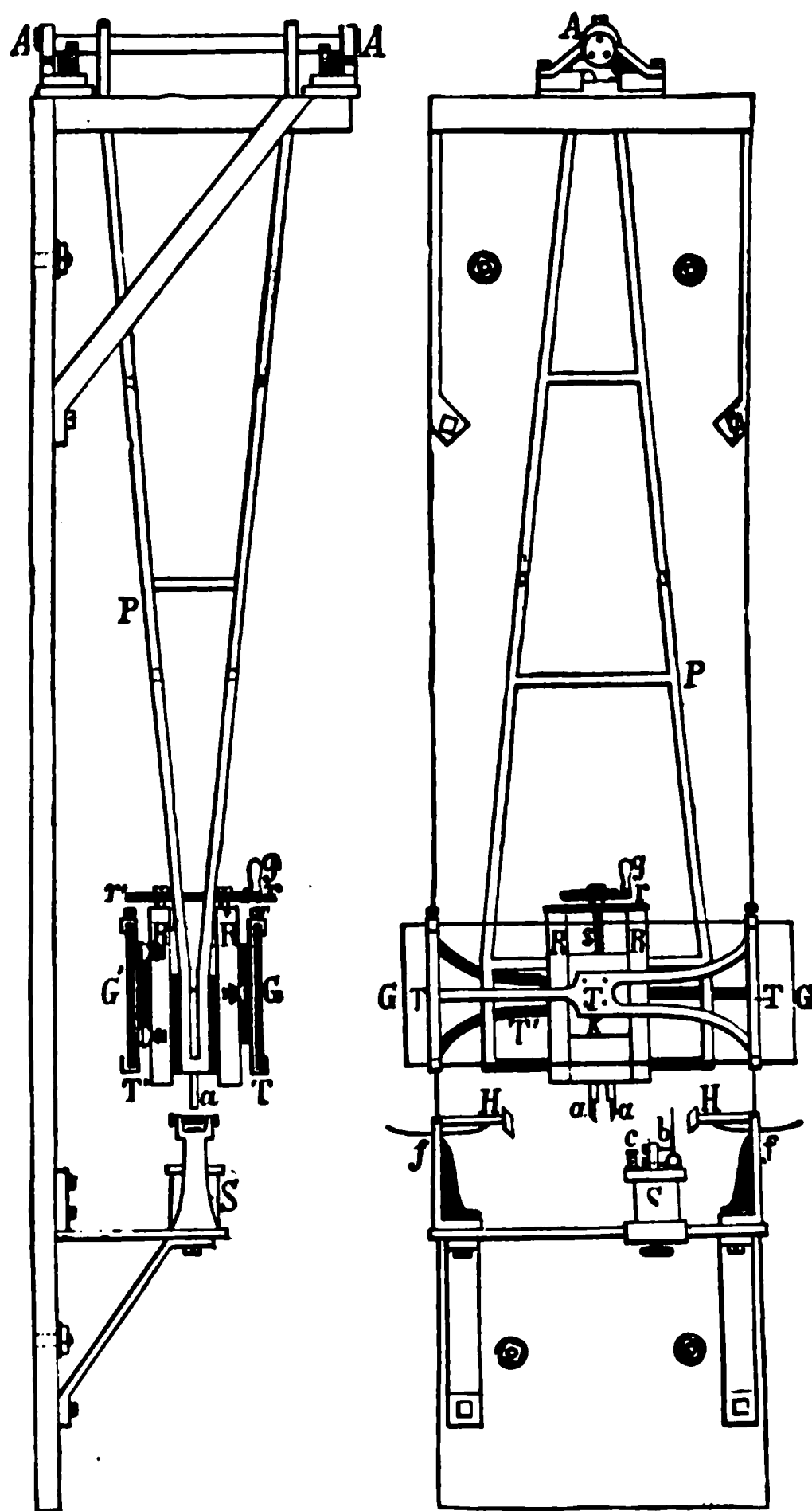


FIG. 256.—Pendulum myograph; at the left, as seen from the front: *A*, bearings on which the pendulum swings; *P*, pendulum; *G*, *G'*, glass plates carried in the frames *T*, *T'*; *a*, pin which opens the trigger-key. The key, when closed, is in contact with *c*, and so completes the circuit of the primary coil (Stewart).

*Time-markers or Chronographs.*—In order to know and record the length of time consumed by various phenomena which are the subject of investigation, various forms of time-markers are used which make a record on the drum at the same time that the myo-

gram is being made. Such an one is the *electric signal of Deprez* (Fig. 258), which is an electromagnet whose circuit is closed and opened by the second pendulum of a clock or a metronome. Or for this purpose a tuning-fork may be used which vibrates

FIG. 257.—Time-marker; arrangement for marking two intervals: *D*, seconds pendulum, with platinum point, *E*, soldered on; *A*, mercury trough, into which *E* dips at the end of its swing; *B*, Daniell cell; *C*, electromagnets, which draw down writing-lever *F* when the current is closed by *E* dipping into *A*. *G*, spring (or piece of India rubber), which raises *F* as soon as current is broken (Stewart).

FIG. 258.—Electromagnetic time-marker connected with metronome. The pendulum of the metronome carries a wire which closes the circuit when it dips into either of the mercury cups, *Hg* (Stewart).

one hundred times in a second, the writing-point being attached to one of its prongs.

*Moist Chamber.*—In order to preserve the preparation in as normal condition as possible during an experiment, it is enclosed in a chamber the air of which is kept moist.

*Simple Muscular Contraction.*—When the muscle-nerve preparation is stimulated by a single induction shock, a single contraction of the muscle results; this is a *twitch* or a *simple muscular*



contraction, and its myogram is shown in Fig. 259. This is a *simple muscle-curve*.

*Latent Period*.—The moment that the stimulus reaches the muscle is represented by *a* in the illustration, but the upward

FIG. 259.—Myogram from gastrocnemius muscle of frog; beneath, the time is recorded in 0.005 second: *a*, moment of excitation; *b*, beginning of contraction; *c*, height of contraction; *d*, end of contraction (Lombard).

curve begins at *b*. So that between these events there is an interval of 0.006 second, as shown by the lowest line, in which the curves are made by a time-marker. This interval is the *latent period*. At *b* the curve begins rapidly to rise, then more slowly,

FIG. 260.—Superposition of contractions: 1 is the curve when only one stimulus is thrown in; 2, when a second stimulus acts at the time when curve 1 has nearly reached its maximum height (Stewart).

when it reaches its highest point, *c*. Then, as the muscle begins to relax, there is a downward curve until the line is reached from which the curve started, this line being the *abscissa*; the descending curve shows that the relaxation is at first rapid, then becomes slower, and occupies a longer time than the contraction. From *a* to *b* occupies about 0.006 second; from *b* to *c*, about 0.05 second; from *c* to *d*, about 0.07 second. *Helmholtz*, in his experiments

upon the frog's gastrocnemius, found that the latent period occupied  $\frac{1}{100}$  second; the rise of the curve, or the *stage of contraction* proper,  $\frac{4}{100}$  second; and the fall or *stage of elongation*,  $\frac{5}{100}$ : or

FIG. 261.—Development of incomplete tetanus and contracture, by indirect stimulation. A gastrocnemius muscle of a frog was indirectly stimulated by breaking induction-shocks, of medium strength, applied to the sciatic nerve. The rate was about 8 per second, as shown by comparison of the seconds traced at the bottom of the figure with the oscillations caused by the separate contractions.

$\frac{1}{10}$  second in all. A close inspection of the myogram will show a slight rise after *d*; this is due to the elasticity of the muscle, and constitutes the *stage of elastic after-vibration* or *contraction-remainder*. Sometimes more than one of these curves are produced. Since the time of Helmholtz's experiments other observers have found that the true latent period is much shorter, certainly not more than  $\frac{1}{4000}$  second, and probably even shorter than this, for

FIG. 262.—Effect of rapid excitations to produce tetanus. Experiment with a gastrocnemius muscle of a frog, excited directly with breaking induction-shocks of medium strength, at the rate of 33 per second. The weight was about 15 grams. The time record gives fiftieths of a second (Lombard).

it is highly probable that changes begin immediately in the muscle upon the receipt of the stimulus, although these changes are not at once apparent. The muscle-curve differs in the muscles of different animals and also in those of the same animal.

*Summation of Stimuli.*—If a muscle which has been stimulated is again stimulated before the effect of the first stimulation has

passed, a second curve will be produced, which will be higher than the first (Fig. 260), due to the addition of the second stimulation to the first. This is the *summation of stimulation, summation of effects, or superposition of contraction*.

**Tetanus.**—When a series of stimuli are added one to another before the effects of the preceding ones have passed, so that the muscle at no time becomes completely relaxed, the condition of *tetanus* is produced: *incomplete tetanus*, if the effect of each stimulation can be seen in the separate curves (Fig. 261), and *complete tetanus*, where these have disappeared and their place is taken by a

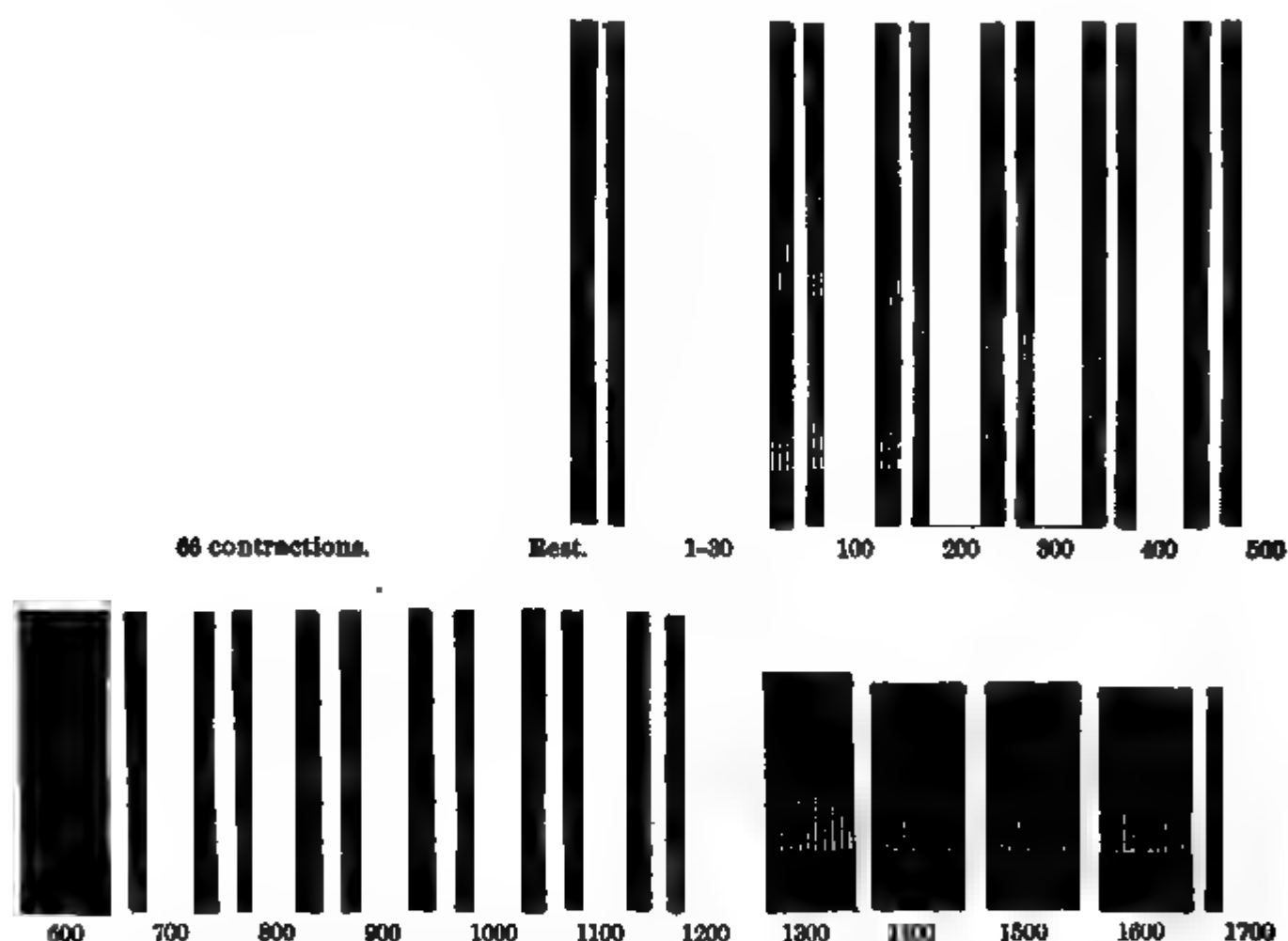


FIG. 263. —Effect of fatigue on the height of muscular contractions. The figure is a reproduction of parts of a record of over 1700 contractions made by an isolated gastrocnemius muscle of a frog. The contractions were isotonic, the weight being about 20 grama. The stimuli were maximal breaking induction-shocks, and were applied directly to the muscle at the rate of 25 per minute. Between the first group of 66 contractions and the following groups a rest of five minutes was given; after this rest the work was continued without interruption for about one and a half hours. The second group of contractions, that immediately following the period of rest, contains the first 20 contractions of the new series; the next group the 100th to the 110th; the next the 200th to the 210th, and so on (Lombard).

continuous line (Fig. 262). *Voluntary tetanus* is the term applied to the normal voluntary contraction of a muscle. The impulses sent out by the nerve-cells are generated and emitted with such frequency as to produce tetanus, and not a simple contraction.

The character of the simple muscle-curve is modified by:

1. The load ; 2. The temperature ; 3. Previous stimulation ; 4. The character of the muscle itself ; and 5. Drugs.

1. *Effect of the Load*.—The extent to which a muscle contracts is increased up to a certain point with the increase of the load ; but when this point is reached it diminishes, and if the load is sufficiently increased, its power to lift it at all ceases.

2. *Effect of Temperature*.—Up to a certain point cold increases the contraction ; beyond this point it diminishes it ; moderate warmth also increases the height of the contraction, but excessive heat (exceeding  $40^{\circ}$  C.) coagulates the proteids of the muscle, producing *heat-rigor*.

3. *Effect of Previous Stimulation*.—When a muscle is stimulated, each curve is a little higher than the preceding one for a time, the curve being called a *staircase* ; then, as the stimulation is continued, the curve falls, and finally there is no response to the stimulation—the muscle is *fatigued*.

*Cause of Fatigue of Muscles*.—This is explained in the case of the muscle-nerve preparation by the fact that the destruction or katabolism of the muscular tissue predominates over its anabolism or building up, and after a time its contractile power is lost.

FIG. 264.—Myogram of muscle poisoned with veratrin and that of a normal muscle: a, myogram from a normal gastrocnemius muscle of a frog—the waves at the close are due to the recoil of the recording lever; b, myogram from a gastrocnemius muscle poisoned with veratrin, recorded at the same part of the drum (Lombard).

Fatigue also occurs as a result of the accumulation of the products of contraction, sarcolactic acid and acid potassium phosphate, which to a certain extent act to prevent contraction, and when these are removed by the circulating blood during a period of rest following muscular activity, the contractile power is restored.

In the fatigue of muscles which follows their use as the result of volition, the cause is chiefly in the nerve-cells in which the voluntary impulses are generated.

4. *Effect Due to the Character of the Muscle*.—Some muscles contract more slowly than others, even in the same individual ; as,

for instance, those of the leg than those of the arm. The same difference is seen in the corresponding muscles of different animals.

5. *Effect of Drugs.*—The effect of drugs upon muscular contraction is well illustrated by injecting veratrin under the skin of a frog: the principal characteristic of the muscle-curve produced being the extreme prolongation of the period of relaxation (Fig. 264).

*Rigor Mortis.*—It has already been stated (p. 62) that the coagulation of the muscle-plasma is the cause of *rigor mortis* or *cadaveric rigidity*, in which the muscle becomes opaque and stiff, and loses its elasticity and extensibility; at the same time it becomes warmer and acid in reaction. Rigor usually appears in from one hour to five hours after death, although this is subject to great variation, coming on more rapidly in muscles that are feeble than in those that are strong and vigorous. Thus in persons who have been in good health, dying suddenly, it comes on slowly; while when death occurs after protracted illness it comes on quickly, and remains but a short time. Animals which have been hunted, and whose muscles are consequently exhausted by fatigue, are the subjects of early rigor mortis. There are, however, instances in which rigor has come on very early in those who were presumably in health at the time, although it is possible that these were not exceptions, and that the cause of the early appearance was due to muscular exhaustion; as, for instance, soldiers killed in battle being found with one eye closed and the other open in the act of taking aim. It has been said that after death from lightning or in the heat of passion, rigor mortis is entirely absent; but it is more than probable that in such cases it comes on early and disappears without having been observed.

Rigor mortis, as a rule, is first observed in the neck and lower jaw, then in the upper, and later in the lower extremities, passing off in the same order. There are, however, exceptions to this. It may remain for from one to six days.

Little is known about rigor mortis of involuntary muscle, although this condition has been seen in the heart, stomach, and uterus.

*Muscular Tone.*—If a relaxed muscle is divided, the two ends separate—*i. e.*, each portion of the divided muscle contracts, so that even in a so-called relaxed muscle this is in a state of *tonic contraction*, and this condition is *muscular tone* or *muscular tonus*. The advantage which accrues from this is that when the muscles are called upon to perform any work they are already in a position to effect results quickly, which would not be the case if it were necessary to bring them from a state of complete relaxation to one of effective contraction. It is as if one desired to

move a boat by a rope, and before exerting any influence on the boat was compelled to take up a considerable amount of slack.

Muscular tone is a reflex action depending upon the reception by the cord of afferent impulses, under which stimulation motor impulses are sent out to the muscles; and if the afferent nerves are cut, the tone disappears.

*Peristalsis*.—The difference in the manner of contraction of voluntary muscle, as the skeletal muscles, as compared with that of involuntary muscle, as that of the intestines, is very marked, for while the action of the former takes place rapidly and throughout the entire muscle, the action of the latter is slow, and moves from point to point as a wave, at a rate of about 30 mm. per second, the contraction occurring at one part of the intestines while it has disappeared at another, the circular coat being especially active in the movement. It is called also *vermicular* contraction. When the movement is in the direction opposite to the normal, as in the intestine from below upward, or in the stomach from the pylorus toward the cardia, it is *reversed peristalsis*.

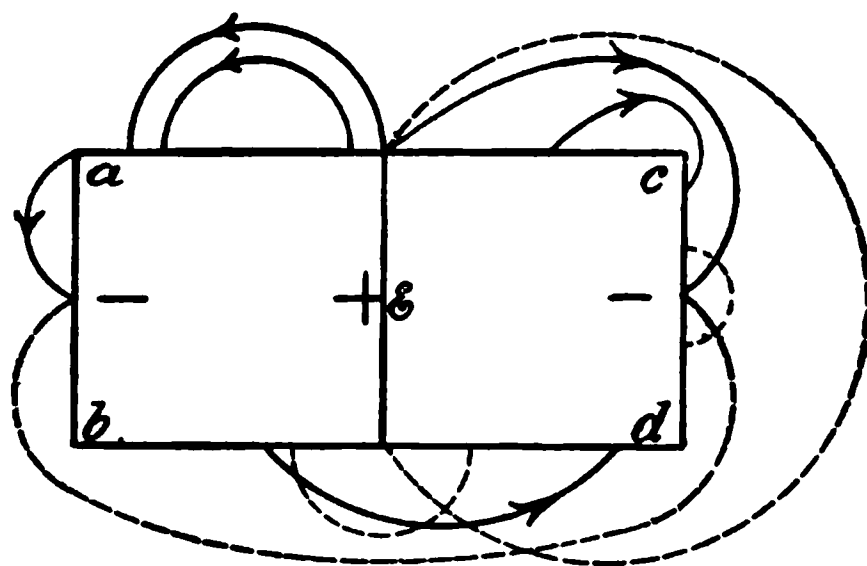


FIG. 265.—Schema to show the direction of currents to be obtained from muscle. The schema represents a cylindric piece of muscle with normal longitudinal surface (*a c* and *b d*), and two artificial cross sections (*a b* and *c d*). The position of the equator is shown by line *e*. The unbroken lines connect points of different potential, and the arrows show the direction which the currents would take were these points connected with a galvanometer. The broken lines connect points of equal potential from which no current would be obtained (Lombard).

*Rhythmicality*.—Involuntary muscular tissue exhibits the property of contracting and relaxing with a certain degree of regularity or rhythm, as in the spleen, where there are a true systole and a diastole, recurring about once each minute, as demonstrated by the oncometer (p. 338).

*Electric Phenomena* (Fig. 265).—A normal muscle in a condition of rest is *iso-electric*—i. e., it is “equally electric throughout, and hence has no electric current”; the same is true of dead muscle. If, however, the muscle is cut, the electrical condition is changed, and if the part that is cut and the normal part are connected to a galvanometer, the movement of the magnet at once

demonstrates the existence of an electric current flowing from the normal to the cut portion. If the muscle is caused to contract, the needle of the galvanometer will return to the position of rest. The first current was formerly called the *current of rest*, but is now known as the *current of injury* or *demarcation current*; while the second is the *current of action*, or *negative variation current*.

Du Bois Reymond explained the current of rest by supposing that in the normal muscle at rest there were electric currents due to the fact that muscle was made up of electromotive molecules, and that each of these molecules is positive at the center and negative at the ends, and this difference of electric tension becomes manifest when the muscle is cut and the negative ends are exposed. Hermann, however, denies the existence of currents in

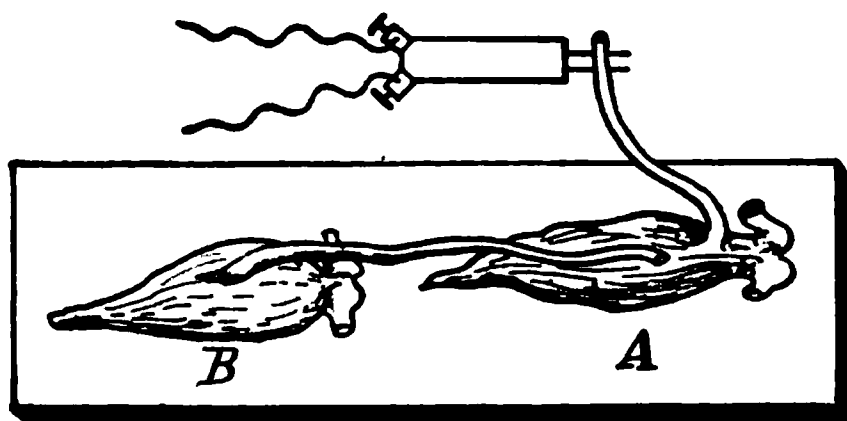


FIG. 266.—Secondary tetanus (Lombard).

normal muscle, and attributes their generation to the injury to the muscle caused by its action, chemic changes being thus brought about. Other injury than cutting will produce the same result, and as these changes take place at the point between the normal and injured tissue the term “demarcation” has been applied to the current thus produced.

It should be said, however, that there are authorities who hold with Du Bois Reymond that normal muscle in a condition of rest is the seat of electromotive forces, which require changed conditions in muscle to bring them forth.

It has been already stated that dead muscle is iso-electric; dead muscular tissue is, however, electrically negative to normal living muscle.

*Secondary Contraction* (Fig. 266).—To demonstrate secondary contraction two nerve-muscle preparations are made, and the nerve of one is placed upon the muscle of the other. Such an arrangement constitutes a *physiologic rheoscope* or *rheoscopic frog*. When the nerve of the first preparation is stimulated, not only its muscle, but also that of the second preparation, contracts. If the stimulation is single, a secondary contraction or twitch results; while if the stimuli cause tetanus of the first muscle, there will be *secondary tetanus* of the second muscle.

The explanation of these secondary contractions would seem to be that the current passes through the first preparation into the second ; but if the nerve of the second is tied, the secondary contraction does not take place, so that this explanation is not a true one. Du Bois Reymond's explanation is that each stimulus applied to the first nerve causes a contraction of its muscle and a current of action, which stimulates the nerve of the second preparation, and a contraction of its muscle follows.



## IV. NERVOUS FUNCTIONS.

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### GENERAL CONSIDERATIONS.

THERE is a most intimate relationship existing between the different organs of the body—so intimate, indeed, that not one of the whole number can be said to be entirely independent of the others. Many illustrations of this dependency might be given, but one will suffice.

The respirations of an individual at rest are not far from 16 per minute, and the pulsations of the radial artery are, under the same condition, about 70. If, now, he exercises violently, the respirations will be found to have greatly increased, amounting perhaps to 30 per minute, while at the same time the pulsations of the artery will have reached 120 per minute. Is this change from the quiescent condition a mere coincidence, or is there a reason for it? If the latter, how has the change been brought about?

During a resting condition the muscles of the body do not make great demand upon the blood, and with the heart beating 70 times per minute the muscles, as well as the other tissues, are receiving all the material they need for the performance of their functions. The 16 respirations a minute are also sufficient to supply the blood with all the oxygen required and to remove from it the necessary amount of carbon dioxid. When, however, the muscles are called upon for the increased exertion above referred to, they must have a greater supply of the necessary materials, to furnish which a larger amount of blood must be sent to them. Then, too, as a result of the extra work, more muscular tissue is wasted, and the waste must be taken away rapidly to the organs whose duty it is to eliminate it. To send the larger supply of blood the heart must beat faster, and to provide the increased oxygen and to remove the additional carbon dioxid the respiratory movements must be more rapid. The muscles of the body have not the power within themselves to increase their activity, but when acted upon properly from without they have. Neither has the heart-muscle the power to beat more quickly until influenced thereto by some influence outside itself. Equally powerless are the agencies which produce the respiratory movements. These outside influences, by which the muscles contract and by which the heart and the respiratory apparatus act in harmony, are

derived from the nervous system, a collection of organs one of whose functions is to cause the different organs to act harmoniously. The effect of a want of harmony under the circumstances just supposed would be most disastrous. If the nervous force was not at command to make the muscles respond when their increased action was desired, there would be a condition of paralysis, or if, when the muscles attempted to perform this added task, the heart should fail to respond, the effort would be fruitless; and equally unavailing would be the attempt if at the crucial moment the lungs and other respiratory organs should be unresponsive. Many other illustrations of the interdependence of the organs might be given, but a little reflection will suggest them almost *ad infinitum*.

The simplest movements that are made require for their performance the conjoint action of several, often many muscles, and were it not for the exciting and controlling power of the nervous system, instead of the harmony which is everywhere and at all times apparent, there would result the utmost confusion.

In what has been said thus far reference has been had only to the individual, as if he was alone on the face of the earth and interested only in himself; but there are other human beings with whom he is constantly brought into relation, and a world of other animate objects as well as an infinite amount of inanimate matter. This relationship is also accomplished through the nervous system, principally by means of the special senses. It will, therefore, be seen that the nervous functions are those which bring the different organs of the body into harmonious relations with one another, and, in addition, bring the individual, through the special senses—sight, hearing, etc.—into relation with the world outside him.

The nervous system is made up of collections of nervous tissue, which is composed of two kinds of matter—nerve-fibers and nerve-cells, with neuroglia; these have been already described (p. 63).

## NERVES.

Nerve-fibers associated together form nerves, and these conduct impulses from within outward, from without inward or from one nerve-center to another. Whether it is the function of a given nerve to do the one or the other does not depend upon anything in the nerve itself, but upon its relations; and there is every reason to believe that were it possible to separate a nerve from its anatomic connections and attach it to different structures, it would be just as capable of acting in its new relations as it did in the old; just as a copper wire will carry equally well a current of electricity to ring a bell or to supply a motor or to turn a hand on a dial: The result depends not upon the wire, but upon the mechanism with which it is in connection.

**Classification of Nerves.**—There are three kinds of nerves, classified according to the direction in which they carry impulses: 1. Efferent; 2. Afferent; and 3. Intercentral.

**Efferent Nerves.**—Inasmuch as nerves of this kind carry impulses away from nerve-centers, they are also called *centrifugal* nerves. They were formerly spoken of as motor nerves. All motor nerves are efferent, for they carry impulses outward, but all efferent nerves are not motor. A nerve which carries an impulse to a muscle, and thus brings about motion, is properly called a “motor nerve”; but one that conducts an impulse to a gland, the results of which are the activity of its cells and the production of a secretion, is improperly named a motor nerve, although it is unquestionably an efferent nerve. *Secretory* is a much more appropriate name. Efferent nerves may be divided as follows: (1) motor; (2) vasomotor; (3) accelerator; (4) secretory; (5) trophic; and (6) inhibitory.

*Motor nerves* terminate in muscles, and convey to them impulses which cause and regulate their contraction.

*Vasomotor nerves*, although distributed to the muscular tissue of blood-vessels, and thus act as motor nerves, regulate the amount of blood supplied to a part, and it seems wise to separate them from the purely motor nerves and put them in a class by themselves.

*Accelerator nerves* are nerves which carry impulses that increase the rhythmic action of an organ, as the sympathetic nerves to the heart.

*Secretory Nerves.*—The impulses which these nerves carry to glands bring about their secretion. The chorda tympani is a striking example.

*Trophic nerves* are supposed by some to govern the nutrition of the structures to which they are distributed, entirely independently of the regulation of the blood-supply. It is still a mooted question whether such nerves exist.

*Efferent inhibitory nerves* carry impulses which restrain or inhibit the action of the organs to which they are distributed. The pneumogastric, so far as the heart is concerned, is such a nerve. Without its restraining influence the heart would beat much faster.

**Afferent Nerves.**—The fact that these nerves carry impulses to the nerve-centers has led to their being called also *centripetal* nerves. They were formerly called *sensory* nerves, but there is the same impropriety in using these terms synonymously as in the case of efferent and motor nerves. All sensory nerves are afferent, but all afferent nerves are not sensory. Afferent nerves may be divided as follows, although the distinction is by no means so well marked as in the efferent nerves: (1) Sensory; (2) nerves of special sense; (3) thermic nerves; (4) excitoreflex; and (5) inhibitory.

*Sensory Nerves.*—When these nerves are stimulated an impulse is carried to a nerve-center; if this center is the brain, the sensation may be a conscious one, and may or may not be painful.

*Nerves of Special Sense.*—The impulses carried by these nerves do not give rise to pain, but with each nerve is connected a special sensation: With the olfactory, the sense of smell; with the optic, the sense of light; and with the auditory, the sense of hearing.

*Thermic Nerves.*—It is believed by some writers that there are special nerves which convey the sense of temperature only; but this is still an unsettled question.

*Excitoreflex Nerves.*—In these nerves there is an impulse carried to a nerve-center without producing a conscious sensation: this center is excited, and from it or from another center with which it is in communication there goes out an impulse that, if it is a gland to which it is distributed, produces secretion: such a nerve would be an *excitosecretory* nerve. Or if it is distributed to a muscle, it produces motion, and would in that case be considered an *excitomotor* nerve.

*Afferent Inhibitory Nerves.*—The afferent inhibitory nerves are also called *centro-inhibitory*, to distinguish them from the efferent inhibitory nerves. The centro-inhibitory nerves carry impulses to nerve-centers, which are so affected as to prevent them from sending out impulses. A familiar instance is that of pinching the lip to prevent sneezing. It is, however, doubtful whether there exists a separate class of nerves performing this function, rather than ordinary sensory fibers which act in this peculiar manner for the moment.

*Intercentral Nerves.*—The nerve-centers are intimately connected with one another by nerves which are neither afferent nor efferent, and which are called *intercentral*. As has been said, even the simplest movements of the body bring into action several, and sometimes many muscles; of course, this action is more obvious in complex movements. To accomplish this, various nerve-centers must be at work; and that they may act harmoniously and produce coördinated movements it is essential that they should be in intimate relationship. Study for a moment the intricate mechanism brought into play in the ordinary act of picking up a pin from the floor, and it will be readily understood how essential it is that the nerve-centers responsible for these movements should act in the most perfect harmony, sending to each muscle just the right amount of nerve-force and at exactly the right moment; otherwise the act could not be accomplished in the perfect manner that it is.

**Determination of the Function of a Nerve.**—The function of a nerve may be determined by (1) dividing it, and observing what function has been lost; or (2) stimulating it, and observing the effect of the stimulation. Thus when a motor nerve is divided,

there is a loss of power, or *paralysis of motion*, in the muscle supplied by the nerve. If, on the other hand, a galvanic current is passed through the nerve, there will follow contraction of the muscle. Similarly a *paralysis of sensation* will follow division of a sensory nerve; and when such a nerve is stimulated, sensation will result. When a nerve is thus divided, one portion will remain in communication with the nerve-center, and is called the *central* or *proximal* end; while the other, which remains in communication with the periphery, is the *distal* or *peripheral* end. Stimulation of the central end of a motor nerve produces no effect; while the motion referred to above results from stimulation of its peripheral end. In the case of a sensory nerve, it is the reverse.

**Wallerian Degeneration.**—When a nerve is divided the first result is a loss of its function. Afterward the nerve undergoes Wallerian degeneration, which results in changes in its structure that can readily be seen. Inasmuch as each nerve-fiber develops from a cell which later nourishes it, if the connection between the two is severed, the nerve-fiber undergoes Wallerian degeneration, and in the case of a nerve which is made up of nerve-fibers the whole nerve undergoes this change. This degeneration consists, in the case of medullated nerves, in the death of the axis-cylinder, the breaking up of the medullary sheath into drops of myelin, which are later absorbed, and the multiplication of the nuclei of the primitive sheath. In non-medullated nerves the only result is the death of the axis-cylinder. Degeneration begins very soon after the section—within a day or two—and throughout the entire severed portion of the nerve at the same time. Thus the course of a nerve, or a collection of nerves, may be traced throughout its entire extent. These changes are believed to be due to the severance of the nerve from its trophic center. If an anterior root of a spinal nerve is divided, the distal end, being separated from the gray matter of the cord which is its center of nutrition, undergoes degeneration, while the end which remains connected with the cord retains its integrity. If a posterior root is divided between the cord and the ganglion, the degeneration takes place between the cord and the ganglion; while if divided below the ganglion, the degeneration takes place in that portion separated from the ganglion, showing that the ganglion is the nutritive center for the posterior root.

**Regeneration of Nerves.**—If the two ends of a divided nerve are brought together and retained there, a regeneration may take place, and the new structure has all the properties of the original nerve. It will be remembered that in the degeneration which follows division of a nerve there is an increase in the nuclei of the sheath. These form a continuous thread of protoplasm within the old sheath, and around this protoplasm a new sheath develops, the whole forming an embryonic nerve-fiber,

which unites with the proximal portion of the old fiber still in connection with its nutritive center, and hence has undergone no degenerative change. Such a regenerated fiber has both conductivity and irritability, the former appearing as early as the third week, but the latter not manifesting itself until afterward. At this period of the regeneration there is neither myelin nor axis-cylinder, and the fiber is responsive to mechanical stimuli, but not to induction shocks, which latter property returns only after the axis-cylinder is developed. The medullary substance later appears and forms a tube; and still later the axis-cylinder is formed, having its origin in the central end of the nerve—i. e., the portion which is still in communication with the cell from which the original axis-cylinder was developed. The complete regeneration of a nerve may take months.

So far as known, regeneration does not occur in the central nervous system.

### NERVE-IMPULSES.

The function of nerve-fibers is to conduct impulses, and this from centers to the periphery, from the periphery to centers, or from one center to another. Although much study has been given to the subject, exactly what a nerve-impulse is has never been determined. Except an electrical change in the nerve itself, and the results of the reception of the impulses at the termination of the nerve, as motion in a motor nerve, secretion in a secretory nerve, etc., there is no evidence of the fact that impulses have travelled over the nerve. Chemical, mechanical, or thermic changes, if they occur, have never been demonstrated.

The stimuli which excite muscle will also stimulate nerves; these are electrical, mechanical, chemical, and thermic; and what has been said of these applies in general to nerves. It should be called to mind, however, that induction-shocks stimulate nerves more powerfully than a voltaic current; while in the case of muscle it is the voltaic current which is the more powerful stimulus.

**Velocity of Nerve-impulses** (Fig. 267).—In the motor nerves of human beings nervous impulses travel at the rate of 33 meters a second, and in sensory nerves, from 30 to 33 meters in the same length of time.

**Electrotonus.**—Although contraction of a muscle takes place at the make and break of a constant current which is passed through the nerve distributed to it, and although no apparent change takes place in the nerve at either of these moments, or indeed while the current is passing, still during the latter period important changes are actually taking place, though they are not visible; these are changes in the electrical condition of the nerve, in its *excitability* and also in its *conductivity*, and are collectively



called *electrotonus*. This has been concisely defined as "a change of condition in nerves traversed by an electric current." It also occurs in muscles.

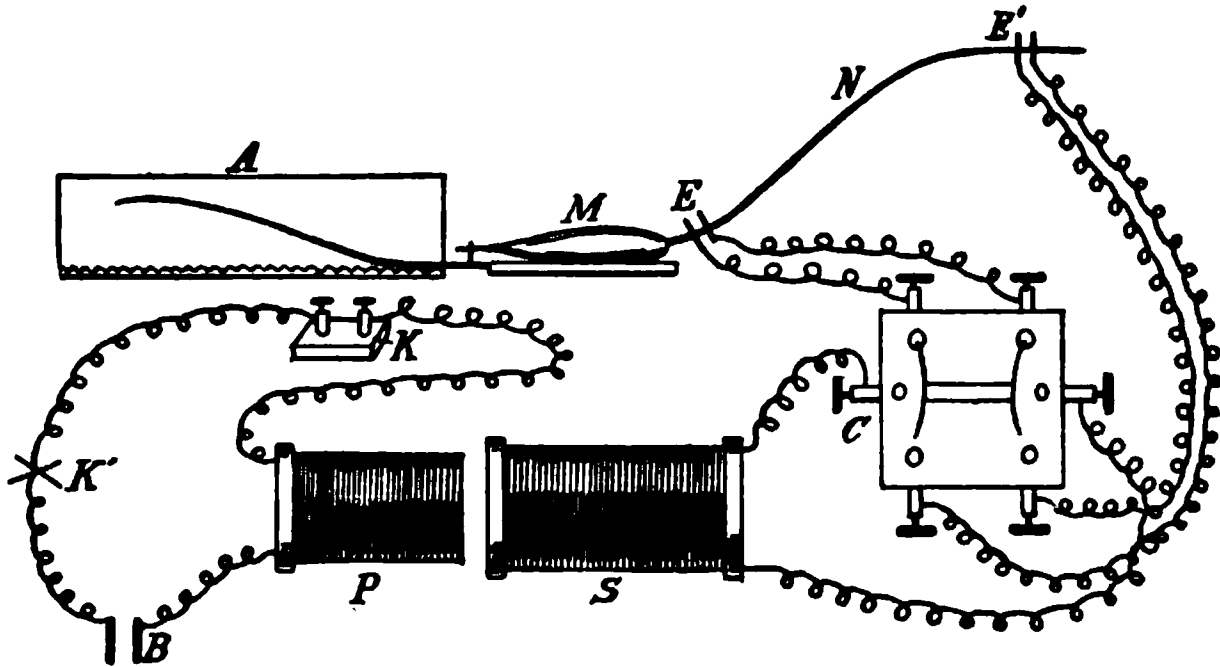


FIG. 267.—Arrangement for measuring the velocity of the nerve-impulse: *A*, travelling plate of spring myograph; *M*, muscle lying on a myograph plate; *N*, nerve lying on two pairs of electrodes, *E* and *E'*; *C*, Pohl's commutator without cross-wires; *K*, knock-over key of spring myograph (only the binding screws shown); *K'*, simple key in primary circuit; *B*, battery; *P*, primary coil; *S*, secondary coil (Stewart).

That an electrical change is produced in a nerve by passing a constant current through it, the *polarizing current*, may be demonstrated by connecting the nerve with a galvanometer. The

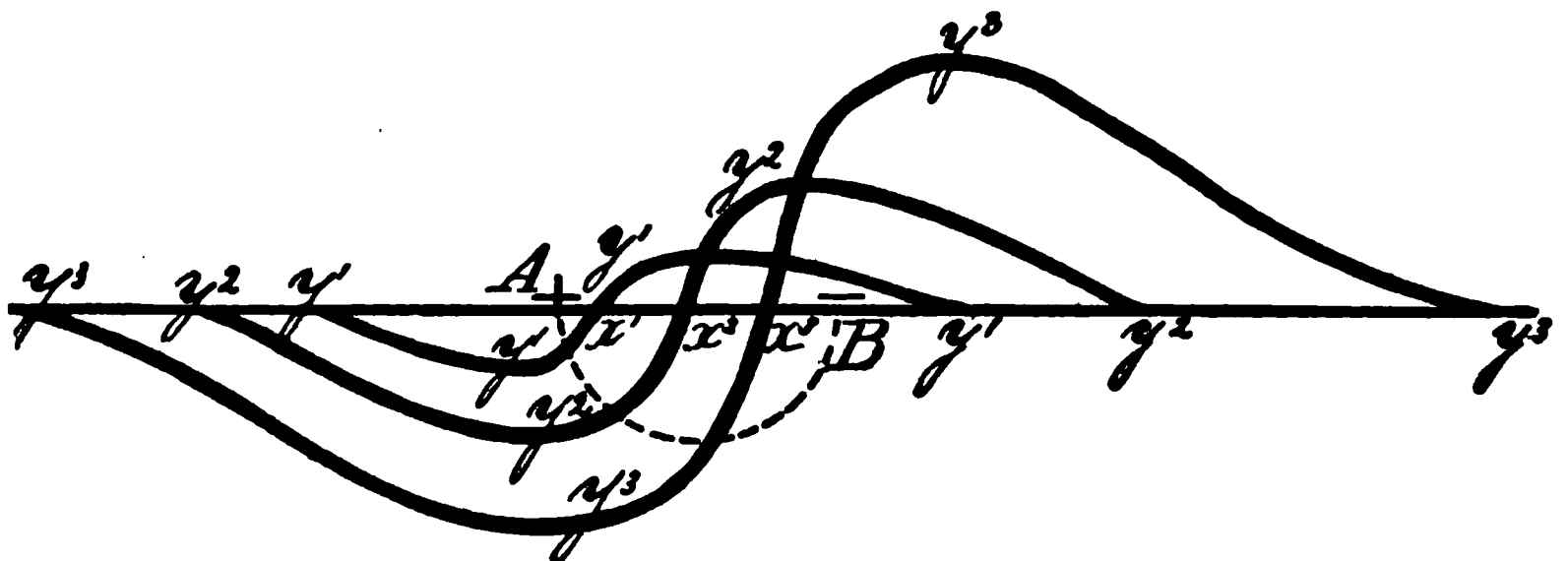


FIG. 268.—Electrotonic alterations of irritability caused by weak, medium, and strong battery currents: *A* and *B* indicate the points of application of the electrodes to the nerve, *A* being the anode, *B* the kathode. The horizontal line represents the nerve at normal irritability; the curved lines illustrate how the irritability is altered at different parts of the nerve with currents of different strengths. Curve  $y^1$  shows the effect of a weak current, the part below the line indicating decreased, and that above the line increased irritability; at  $x^1$  the curve crosses the line, this being the indifferent point at which the katelectrotonic effects are compensated for by anelectrotonic effects;  $y^2$  gives the effect of a stronger current, and  $y^3$ , of a still stronger current. As the strength of the current is increased the effect becomes greater and extends farther into the extrapolar regions. In the intrapolar region the indifferent point is seen to advance with increasing strengths of current from the anode toward the kathode.

current near the kathode is the *katelectrotonic current*, while that near the anode is the *anelectrotonic current*. These currents occur only as the result of passing a constant current through a nerve,

and cease when the current ceases. They exist in living medullated nerves only, or if at all in degenerated nerves but to a slight degree.

At the time of the passage of the current there is an increase in the excitability or irritability of the nerve in the kathodic region, and a decrease in the anodic region; the increase is *katelectrotonus*, and the decrease, *anelectrotonus*. After the opening of the current the conditions are reversed, the excitability being temporarily increased in the anodic, and decreased in the kathodic

FIG. 269.—Diagram of changes of excitability and conductivity produced in a nerve by a voltaic current: E, changes of excitability during the flow of the current, according to Pflüger. The ordinates drawn from the abscissa axis to cut the curve represent the amount of the change. C (1), changes of conductivity during the flow of a moderately strong current; conductivity greatly reduced around kathode; little affected at anode. C (2), changes of conductivity during flow of a very strong current; conductivity reduced both in anodic and kathodic regions, but less in the former. C', changes of conductivity just after opening a moderately strong current; conductivity greatly reduced in region which was formerly anodic; little affected in region formerly kathodic (Stewart).

area. The *indifferent point* is the point at which there is no change in the excitability of the nerve, where the katelectrotonic and anelectrotonic effects counteract each other; this will change its position according to the intensity of the current, approaching the kathode as the intensity increases. Fig. 268 shows the changes which take place according as the intensity of the current is increased.

The *conductivity* of a nerve is also affected by the constant current, the changes being shown in Fig. 269.



## THE NERVOUS SYSTEM.

The nervous system is divided into two subdivisions: the cerebrospinal system and the sympathetic system.

The cerebrospinal system includes the brain and spinal cord, which together form the cerebrospinal axis, and the nerves which come from them, namely, the cranial and spinal nerves.

### SPINAL CORD.

The spinal cord is situated in the vertebral canal, and is covered by three membranes—the dura mater, arachnoid, and pia mater. It is about 0.43 meter in length, and, in general, is of a cylindrical shape; it weighs 42.5 grams. It extends from the medulla oblongata above to the first lumbar vertebra below, where it ends in the *filum terminale*, although in fetal life it extends to the bottom of the sacral canal.

**Enlargements of the Spinal Cord.**—Two enlargements along the course of the spinal cord are noteworthy. The *cervical*

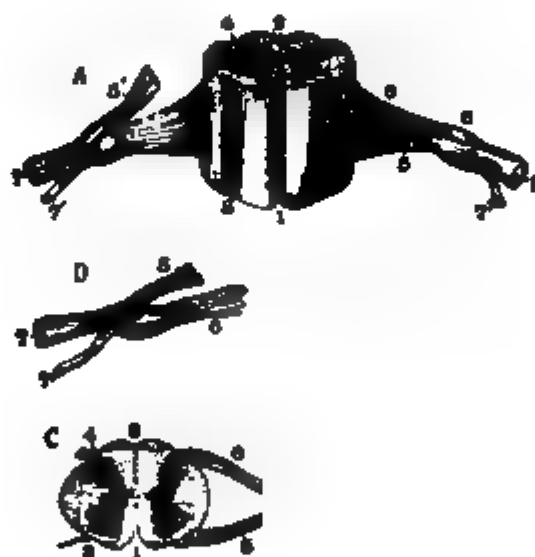


FIG. 270.—Different views of a portion of the spinal cord from the cervical region, with the roots of the nerves. In *A* the anterior surface of the specimen is shown, the anterior nerve-root of its right side being divided; in *B* a view of the right side is given; in *C* the upper surface is shown; in *D* the nerve-roots and ganglion are shown from below: 1, the anterior median fissure; 2, posterior median fissure; 3, anterior lateral depression, over which the anterior nerve-roots are seen to spread; 4, posterior lateral groove, into which the posterior roots are seen to sink; 5, anterior roots passing the ganglion; 5', in *A*, the anterior root divided; 6, the posterior roots, the fibers of which pass into the ganglion, 6; 7, the united or compound nerve; 7', the posterior primary branch, seen in *A* and *D* to be derived in part from the anterior and in part from the posterior root (Allen Thomson).

*enlargement* extends from the third cervical to the first or the second dorsal vertebra, and the *lumbar enlargement* is at the eleventh and twelfth dorsal vertebræ. From the cervical enlargement go off the nerves which supply the upper, and from the lumbar those which supply the lower, extremities.

SPINAL CORD.

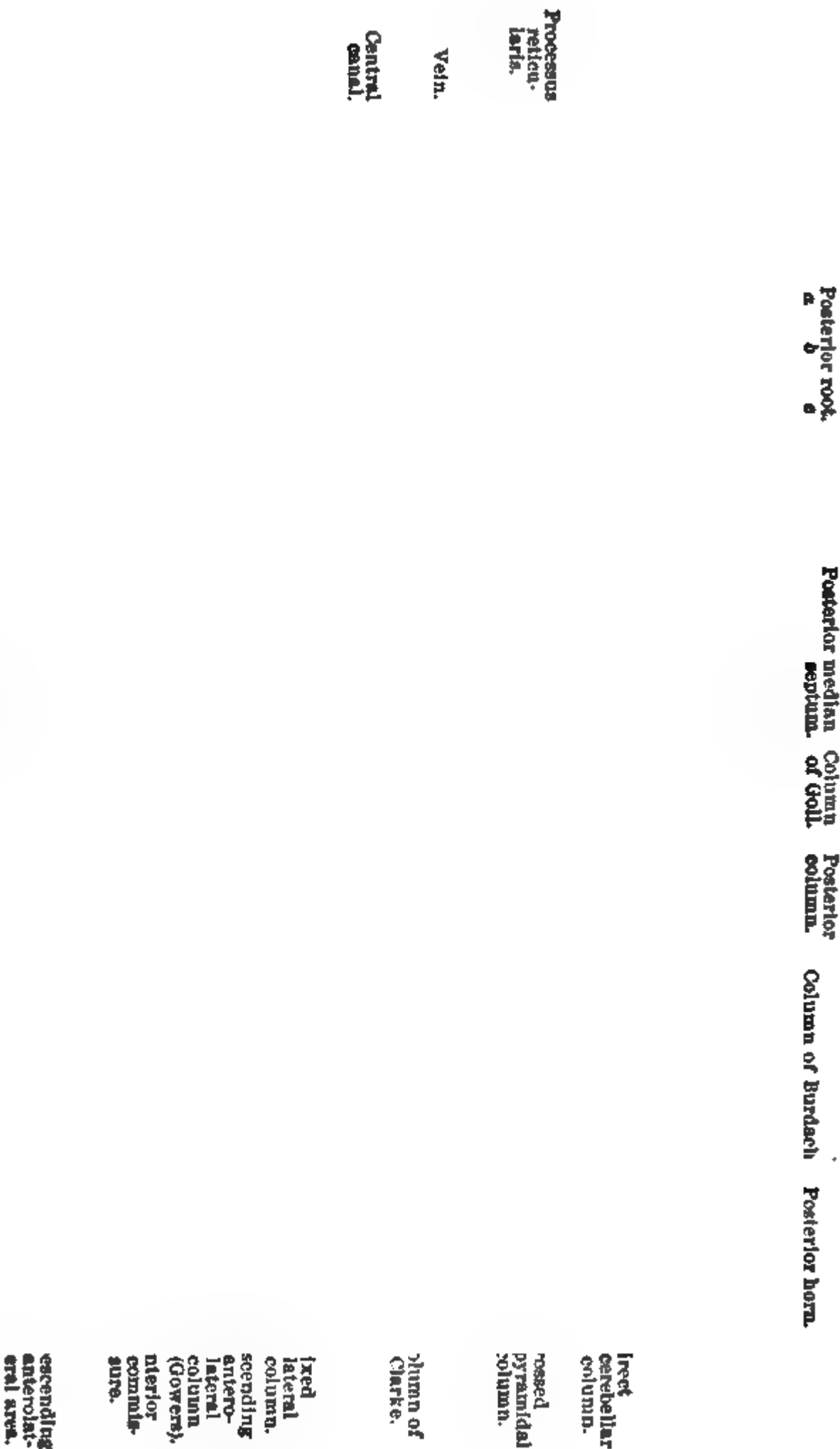


Fig. 271.—Schematic cross-section of the spinal cord, after Professor Ziehen : *a*, *b*, and *c*, bundles of the posterior nerve-root (from von Bardeleben and H. Heckel).

*A**B**C**D*

FIG. 272.—Four cross-sections of the human spinal cord: *A*, cervical region; in the plane of the sixth spinal nerve-root; *B*, lumbar region; *C*, thoracic region; *D*, sacral region;  $\times 7$  (from preparations of H. Schmaus) (Böhm and Davidoff).

**Fissures** (Fig. 270).—On the anterior surface of the spinal cord is a groove, the *anterior median fissure*, which extends to the *anterior white commissure*. On the posterior surface is also a so-called fissure, the *posterior median fissure*, which is filled with connective tissue and blood-vessels, and extends to the *posterior gray commissure*. It will thus be seen that the anterior and posterior fissures nearly divide the cord into two symmetrical halves, which are connected by the *commissures*.

At a little distance from the anterior median fissure on each side is the *anterolateral fissure*. Strictly speaking, this is not a fissure, being rather a line of small openings at which emerge the anterior roots of the spinal nerves. In front of the posterior median fissure and on either side is the *posterolateral fissure*. Here emerge the posterior roots of the nerves. The *posterior intermediate furrow* is between the posterior median and posterolateral fissures.

**Columns.**—The anterior and posterior median fissures divide the cord into two symmetrical halves, and the anterolateral and posterolateral fissures subdivide each half into three columns called *main columns*: anterolateral, posterolateral, and posterior median.

**Anterolateral Column.**—This includes that portion of the cord between the anterior median and the posterolateral fissure. It is divided by some anatomists into an *anterior*, situated between the anterior median fissure and the anterior nerve-roots, and a *lateral*, the portion between these roots and the posterolateral fissure (Fig. 271).

**Posterolateral Column.**—This is the portion between the posterolateral fissure and the posterior intermediate furrow.

**Posterior Median Column.**—This is also called posteromedial column. It is situated between the intermediate furrow and the posterior median fissure. The posterolateral and posterior median are sometimes described together as the posterior column.

**Section of the Spinal Cord** (Fig. 273).—A cross-section of the spinal cord shows a central gray substance and an external white substance. The gray matter presents the appearance of two crescents, with the concavities outward, joined together by a band of gray matter, the *gray commissure*. The points of the crescents are the horns or *cornua*, two anterior and two posterior. The posterior cornua come nearly to the surface of the cord at the posterolateral fissure, while between the surface and the extremities of the anterior cornua there is considerable white matter. The arrangement of the white matter into columns is readily discerned in this section. In the gray commissure is a small canal—the *central canal*—which communicates with the fourth ventricle of the brain, and contains *cerebrospinal fluid*. This is a colorless alkaline fluid containing sodium chlorid and other

inorganic salts, and about 0.1 per cent. of proteids, principally proto-albumose, with some serum-globulin, and rarely peptone. Serum-albumin, fibrinogen, and nucleoproteid are absent. It also contains a non-nitrogenous reducing substance considered by Claude Bernard to be sugar, but by Halliburton to be pyrocatechin derived from the proteids.

The central canal is lined with columnar epithelium, which in fetal life is ciliated, but the cilia are often absent in the adult. The canal is of special interest in connection with the development of the cord. Sections of the cord at different levels show that the white substance is most abundant in the upper part, and

FIG. 273.—Transverse section of half the spinal cord, in the lumbar enlargement (semi-diagrammatic): 1, anterior median fissure; 2, posterior median fissure; 3, central canal lined with epithelium; 4, posterior commissure; 5, anterior commissure; 6, posterior column; 7, lateral column; 8, anterior column (the white substance is traversed by radiating trabeculae of pia mater); 9, fasciculus of posterior nerve-root, entering in one bundle; 10, fasciculi of anterior roots, entering in four spreading bundles of fibers; b, in the cervix cornu, decussating fibers from the nerve-roots and posterior commissure; c, posterior vesicular columns. About half-way between the central canal and 7 is seen the group of nerve-cells forming the tractus intermediolateralis; e, e, fibers of anterior roots; d, fibers of anterior roots which decussate in anterior commissure (Allen Thomson).

gradually becomes less abundant as the examination is made down the cord. The cervical and lumbar enlargements are due to the increased amount of gray matter at these points.

**Minute Structure of the Cord.**—Neuroglia supports both the white and the gray matter of the spinal cord, and occurs also under the pia mater, around the central canal, forming the *substantia gelatinosa centralis*, and at the apex of the posterior horn, forming the *substantia cinerea gelatinosa* of Rolando or *substantia gelatinosa lateralis*.

The white substance is made up of medullated nerve-fibers and blood-vessels, in addition to neuroglia. The medullated nerve-

fibers in sections stained with carmin or anilin blue-black appear as clear areas with the stained axis-cylinder in the center, the clear space being the medullary substance.

The **gray matter** consists of nerve-fibers, of nerve-cells and their processes, together with neuroglia and blood-vessels.

**Tracts of the Cord.**—The course which the nerve-fibers take in the columns of the cord has been determined by two methods: the embryologic and the degenerative.

The *embryologic method*, or method of Flechsig, consists in studying the cord at different stages of its development; and as in some tracts the medullary substance forms at an earlier period than in others, these can be thus differentiated or distinguished from one another.

The *degenerative*, or *Wallerian*, method consists in studying the degeneration which occurs in nerve-fibers when separated from their nutritive or trophic centers (p. 464). Sections of the cord in which the degeneration has taken place are stained with Marchi's solution, consisting of Müller's fluid 2 parts, and 1 per cent. osmic acid 1 part: the degenerated fibers stain black, while the other portion remains practically unstained. A tract in which this degeneration takes place below the injury or point of section is a *descending tract*, and the degeneration is a *descending degeneration*; while a tract in which the process occurs above the lesion is an *ascending tract*, and the change, an *ascending degeneration*.

These methods have demonstrated the following tracts in the cord (Fig. 271), into which the main columns may be considered as divided. Each tract or fasciculus may be considered, Gray says, as a distinct anatomic system and endowed with special functions:

1. *Direct Pyramidal Tract.*—This is also called *fasciculus of Türck*, and is situated in the anterolateral column next to the anterior median fissure. It is continuous with the non-decussating fibers of the pyramid of the medulla. Besides this tract, the anterolateral column contains:

2. *Crossed Pyramidal Tract.*—The fibers of this tract are continuous with those forming the decussation of the pyramid of the medulla.

3. *Direct Cerebellar Tract.*—Continuous with the restiform body.

4. *Anterolateral Ground-bundle.*—Continuous with the *formatio reticularis* of the medulla.

5. *Anterolateral Descending Cerebellar Tract* (Löwenthal).

6. *Anterolateral Ascending Cerebellar Tract* (Gowers).

7. *Tract of Lissauer.*

The posterior column contains:

8. *Posteromedian*, also called *posteromesial* and *column of Goll*, which is continuous with the *funiculus gracilis* of the medulla.

9. *Posterolateral*, also called *column of Burdach*, which is continuous with the funiculus cuneatus.

10. *Comma tract*.

The position and relation of these tracts can be better understood by reference to the illustrations than by any verbal description.

**Grouping of the Nerve-cells** (Fig. 274).—Some of the nerve-cells of the cord are distributed through the gray matter, while others are arranged in groups, the latter being larger, and characterized by their branching; they are *multipolar nerve-cells*.

**Cells of the Anterior Horn.**—In the anterior cornu are three of these groups: 1. Near the tip on the inner side; 2. At the base on the inner side; and 3. On the outer side of the gray matter.

Direct pyramidal column.

FIG. 274.—Schematic diagram of the spinal cord in cross-section, after von Lenhossek, showing in the left half the cells of the gray matter, in the right half the collateral branches ending in the gray matter (Böhm and Davidoff).

Each cell of the anterior cornu gives off an axis-cylinder process which passes out into the anterior nerve-roots.

**Cells of the Posterior Horn.**—These are smaller than those of the anterior cornu, but their axis-cylinder processes do not pass into the posterior nerve-roots.

**Clarke's Column.**—This group of cells is most marked in the thoracic region, and is situated at the base of the posterior cornu. Their axis-cylinder processes pass into the direct cerebellar tract.

**Intermediolateral Tract.**—This group is situated on the outer side of the gray matter in what is called the *lateral horn* between the anterior and posterior cornua.

**Middle Cell-group.**—These lie in the middle of the crescent.

**Nerve-fibers of the Gray Matter.**—These are, as a rule, smaller than those in the white substance. In the posterior cornu

they form *Gerlach's nerve-network*, in which small and larger nerve-fibers exist together. These fibers can be traced to the medullated fibers of the posterior nerve-roots, and also to the processes of the ganglion-cells, thus bringing these cells into connection with the posterior nerve-roots through the network.

The fibers of the anterior horn are directly continuous with the axis-cylinder processes of the ganglion-cells.

The following illustration (Fig. 275) represents the relations between the nerve-cells, the skin, and a muscle.

**Spinal Nerves.**—There are thirty-one pairs of spinal nerves, which are distributed to the neck, trunk, and extremities. Each

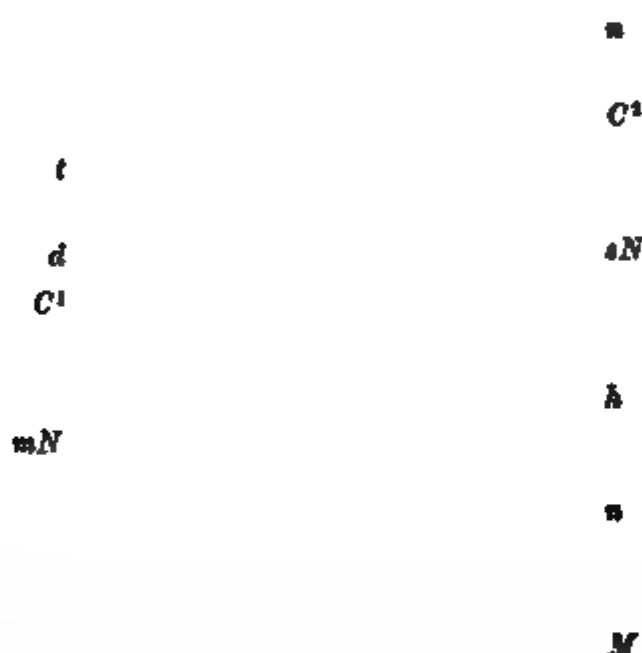


FIG. 275.—Schematic diagram of a sensorimotor reflex arc according to the modern neuron theory; transverse section of spinal cord; mN, motor neuron; sN, sensory neuron; C¹, nerve-cell of the motor neuron; C¹, nerve-cell of the sensory neuron; d, dendrite; a, neuraxis of both neurons; t, telodendrons; M, muscle-fiber; A, skin with peripheral telodendron of sensory neuron (Böhm and Davidoff).

of these arises by two roots; an anterior or motor, and a posterior or sensory root.

**Anterior Roots.**—These are traced through the anterolateral column to the cells of the gray matter of the anterior cornu. Around the cells is an interlacement of ramified nerve-endings, which come especially from the collaterals of the posterior root-fibers and from those of the fibers of the white substance of the cord.

**Posterior Roots.**—These are characterized by the presence upon each of a ganglion, except the posterior root of the first cervical nerve, which frequently possesses no ganglion. These roots have their origin in the cells of the ganglion, and pass into the posterolateral column, some entering the marginal bundle of Lissauer,



and some passing into the posterior cornu. When the fibers of the posterior root enter the cord they bifurcate, one branch passing upward, the other downward. From the main fiber, and also from the branches, pass collaterals, which end in the gray matter in arborization, and in the nerve-cells of the anterior and posterior cornua. In the same manner end the main fiber and its branches; some, however, pass upward in the posterolateral and posteromesial

**FIG. 276.**—Transverse section through half the spinal cord, showing the ganglia: *A*, anterior cornual cells; *B*, axis-cylinder process of one of these going to posterior root; *c*, anterior (motor) root; *D*, posterior (sensory) root; *E*, spinal ganglion on posterior root; *F*, sympathetic ganglion; *G*, ramus communicans; *H*, posterior branch of spinal nerve; *I*, anterior branch of spinal nerve; *a*, long collaterals from posterior root-fibers reaching to anterior horn; *b*, short collaterals passing to Clarke's column; *c*, cell in Clarke's column sending an axis-cylinder (*d*) process to the direct cerebellar tract; *e*, fiber of the anterior root; *f*, axis-cylinder from sympathetic ganglion cell, dividing into two branches, one to the periphery, the other toward the cord; *g*, fiber of the anterior root terminating by an arborization in the sympathetic ganglion; *h*, sympathetic fiber passing to periphery (Ramon y Cajal).

columns, and end in the medulla by arborizing around the cells of the nucleus gracilis and cuneatus.

**Spinal Ganglia.**—The structure of these ganglia has been already described. Beyond the ganglion the two roots unite to form the trunk of the spinal nerve, which passes out through the intervertebral foramen, and gives off a recurrent branch to the dura mater of the cord. It then divides into a posterior division, which is distributed to the posterior part of the body, and an ante-

rior division which goes to the anterior part; each division contains fibers from both roots.

**Functions of the Spinal Cord.**—The functions of the spinal cord are of two kinds: 1. A conductor of impulses, by virtue of the fibrous nervous matter which it contains; and 2. A nerve-center, by virtue of its nerve-cells.

**As a Conductor of Impulses.**—The spinal cord is the principal channel through which all impulses from the trunk and the extremities pass to the brain, and all impulses to the trunk and extremities pass from the brain. If through disease or injury the cord is disorganized at any point, all power to produce voluntary motion in the parts below the injury is lost, and conscious sensation in these parts is from that moment abolished. The cord therefore acts as a conductor of impulses, both motor and sensory, between the brain and the trunk and extremities; the different kinds of impulse follow different paths in the cord.

**Conducting-paths in the Cord.**—The paths by which voluntary motor impulses traverse the cord are fairly well ascertained. These impulses originate in the pyramidal cells of the cerebral cortex, and pass through the pyramids in the medulla, crossing principally at the decussation of the pyramids, and to a less degree in the upper part of the cord, to the opposite side, whence they follow the course of the pyramidal tracts, direct and crossed, arborizing around the cells of the anterior cornua; from which the anterior roots arise to be distributed to the muscles.

The course pursued by the sensory impulses (Fig. 277) is not

FIG. 277.—Schema showing pathway of the sensory impulses. On the left side, *S, S'*, represent afferent spinal nerve-fibers; *C*, an afferent cranial nerve-fiber. This fiber in each case terminates near a central cell, the neuron of which crosses the middle line and ends in the opposite hemisphere (van Gehuchten).

so well understood as is that of the motor. But the best opinions may be summarized as follows :

*Tactile and muscular sense-impressions* pass up the posterior columns to the nucleus gracilis and nucleus cuneatus, by the internal arcuate fibers and fillet to the optic thalamus, by the posterior part of the internal capsule to the Rolandic area of the opposite side.

*Painful impressions*, and those of *heat and cold*, pass up the gray matter of the cord from cell to cell to the optic thalamus, and by the fibers of the corona radiata to the cortex.

Afferent impulses reach the cerebellum by Clarke's column, direct cerebellar tract, restiform body, and inferior peduncles. The fibers composing the tract of Gowers have their origin in cells at the base of the anterior cornu, on the opposite side, and its cerebellar fibers pass to the middle lobe by the superior peduncles.

There are other fibers in the cord, which have their origin in the cerebellum ; but although their existence has been ascertained their destination is not certainly determined, though it is thought by some that they arborize around cells in the anterior cornua.

**As a Nerve-center.**—Besides the function which the cord performs as a conductor of motor and sensory impulses, it also acts as a nerve-center in which, by virtue of its nerve-cells, afferent impulses are received and motor impulses are generated.

Voluntary motion in the extremities, which motion originates in the brain, is abolished when the cord is divided and its anatomic connection with the brain cut off ; but there still remains the power of exciting muscular contractions in these muscles, due to the cells of the cord itself.

**Reflex Action.**—If a frog is decapitated, it has no longer the power of producing voluntary movements ; but if the skin of a foot is irritated by pinching, the foot is pulled away from the source of irritation. This is an instance of reflex action. A slight pinch will cause only the one foot to be withdrawn ; but if it is stronger, the other foot may also be withdrawn. This is known as a *spreading of reflexes*. Such movements are not spontaneous, but they require the application of a stimulus for their production. The irritation does not act upon the muscles directly, but through the medium of nerves, an afferent nerve carrying the sensory impulse inward to the cord, and an efferent nerve conducting a motor impulse outward to the muscles. If either of these nerves is divided, the action does not take place ; nor does it if the gray matter is broken up. For the performance of a reflex act, therefore, three things are necessary—an afferent nerve, a nerve-center, and an efferent nerve, all in a physiologic condition.

This can be readily understood by reference to Fig. 275, where *h* represents the skin, from which passes an afferent nerve to the

center, and C<sup>1</sup> represents a cell in the anterior cornu of the cord, from which passes a motor impulse to the muscle M.

In the human subject, when the cord is injured or diseased at any point, so as to cut off communication between the brain and extremities, but is still intact below this point, tickling of the soles of the feet will be followed by their withdrawal, although the individual will be entirely unconscious of any sensation. This is also an instance of reflex action. As in the frog, so in man, the three structures mentioned must exist in a state of integrity for the performance of this act.

It is not essential, however, that the cord be diseased in order to have it manifest reflex action: this property is one which normally resides in the cord. Thus if the hand comes in contact with a flame, it is immediately withdrawn. This is not a voluntary act, for the act of withdrawal takes place before the sensation of pain is felt in the brain. It is a purely reflex act, in which the gray matter of the cord, after being stimulated by an impulse carried to it by an afferent nerve, generates an impulse which is conveyed by an efferent nerve to the muscles concerned in withdrawing the arm. The afferent nerve, nerve-center, and efferent nerve form a *reflex arc*. If the attention was fixed upon the subject at the time the burn was received, it might be possible to prevent the withdrawal. This would be an instance of *inhibition* of reflex action.

**Reflex Time.**—From the moment when the stimulus is applied to the moment when the reflex action takes place is an appreciable interval of time, part of which is occupied by the passage of the afferent impulse to the center, part by the passage of the efferent nerve to the muscle, part by the latent period of the muscular contraction, and part by the reception of the afferent impulse and the generation of the efferent impulse in the center itself; this latter is the *reflex time*. In the frog it varies from 0.008 to 0.015 second. Heat and an increase in the strength of the stimulation lessen it.

**Reflexes in Man.**—The presence or absence of certain reflexes is made use of to determine the presence or absence of certain diseases in the human subject. They are included in two groups, superficial and deep.

**Superficial Reflexes.**—Of these, there are many, but the principal ones are:

1. *Plantar*.—Tickling the sole of the foot causes its withdrawal.

2. *Gluteal*.—Pricking of the skin over the gluteus causes a contraction of that muscle.

3. *Cremasteric*.—Stimulating the skin on the inner side of the thigh causes a retraction of the testicle.

4. *Abdominal*.—Stimulating the skin of the abdomen causes a contraction of muscles in this region: when this occurs in the epigastric region it constitutes the *epigastric reflex*.

5. *Nasal*.—Stimulation of the nasal mucous membrane causes sneezing.

6. *Conjunctival*.—Touching the eyeball causes closure of the eyelids.

**Deep Reflexes.**—These are called also *tendon reflexes*, but are not true reflexes as are the superficial ones, being caused by direct stimulation of the muscles or their tendons.

1. *Tendo Achillis Reflex*.—If while the extended leg is supported at the knee a hand is firmly pressed against the ball of the foot, a tap on the tendo Achillis causes the gastrocnemius and soleus to contract and draw the heel up quickly. This may exist or not during health.

2. *Ankle-clonus*.—The leg being supported, the ball of the foot is suddenly pressed so as to put the muscles of the calf on the stretch, and there results a series of clonic contractions of these muscles which cease when the pressure is removed. This is absent in health.

3. *Patellar Reflex or Knee-jerk*.—If one thigh is crossed over the other, a tap on the tendon below the patella causes a forward movement of the leg. This is present in health, but may be increased or abolished in disease.

**Other Functions of the Cord as a Nerve-center.**—The power of the spinal cord to respond to afferent impulses independently of the will is of great advantage in preserving the body from *injury*. The attempt to retain one's equilibrium after slipping on a sidewalk, and the raising of the arms in front of the face to ward off an unexpected blow, are both instances of this action.

*Walking, playing on musical instruments*, and similar acts are all performed under the influence of the gray matter of the cord. To start them requires the action of the brain, but when once they are begun their continuance is accomplished by the cord, and the brain can be busy about other things without interfering in the slightest degree with the perfection of their performance. Indeed, any attempt to control them is more apt to hinder than to help them. Thus in coming rapidly down a flight of steps, if the spinal cord is permitted to take charge of the act the descent will be made with ease and safety, but if each step is made as the result of volition, the chances of stumbling or of tripping are very much increased.

The reflex action of the cord may be *diminished* by shock to the nervous system; thus in the frog immediately after decapitation the reflex power cannot be excited, but after a short time it manifests itself under the influence of a stimulus. A similar

diminution of the reflex power of the cord may be caused by opium, by chloroform, and by some other substances, while the reflex action is *increased* by strychnin. If under the skin of the decapitated frog a solution of strychnin is injected, the cord in a short time becomes so irritable that a stimulus which before would have had no effect will now produce the most marked results, a slight blow upon the skin sufficing to throw the animal into a convulsive state. In tetanus the same irritable condition of the cord exists, and in this state the patient may be thrown into convulsions by the simple opening and closing of a door.

**Special Centers in the Cord.**—It is the practice to speak of certain centers as existing in the spinal cord—that is, of definite collections of cells which preside over definite functions. Among these centers the following have been described: Musculo-tonic, respiratory, cardio-accelerator, vasomotor, sudorific, cilio-spinal, genitospinal, anospinal, vesicospinal, trophic, for erection of the penis, for parturition, and others.

**Musculotonic Center.**—This center is continually discharging impulses which keep the muscular system in a condition of slight contraction: this is called *muscular tone*. It is questionable whether this condition is to be attributed to any special center rather than to the action of all those cells whose function it is to send out motor impulses.

**Respiratory Center.**—The respiratory center is in the medulla, but experiments in which this structure has been destroyed while some respiratory movements persisted demonstrate that to a certain extent, doubtless very slight, the spinal cord controls the respiratory processes.

**Cardio-accelerator Center.**—The spinal cord through the cardiac nerves and plexus sends impulses to the heart, causing it to beat more rapidly—that is, they accelerate its movements. These impulses are not constantly emitted as are the inhibitory impulses, which travel by the pneumogastric.

**Vasomotor Center.**—The vasomotor center in the cord is entirely subsidiary to that in the medulla.

**Sudorific Center.**—The existence of special nerves controlling the secretion of sweat seems to be demonstrated. These nerves come from the spinal cord, being a part of the anterior roots.

**Cilio-spinal Center.**—Nerve-fibers pass from this center to the iris, and they are concerned in the dilatation of the pupil. These fibers come out from the cord through the anterior roots of the spinal nerves, from the fifth cervical to the fifth thoracic, and join the cervical sympathetic.

**Genitospinal Center.**—The genitospinal is the center which governs the emission of semen, and is situated in the lumbar region of the cord. Sensory impulses from the glans penis reach this center through afferent nerves and stimulate it, and from it

go out efferent impulses which cause contraction of the muscular fibers of the vasa deferentia, seminal vesicles, and accelerator urinæ, the result of which is to produce an ejection of semen.

**Anospinal Center.**—The act of defecation is governed by the anospinal center and has been already described (p. 266).

**Vesicospinal Center.**—The act of micturition is under the influence of the vesicospinal center. This act has been already described (p. 430).

**Trophic Centers.**—It has already been seen that when nerve-fibers are divided they undergo degeneration, and that this is explained by the fact that under these circumstances their connection with certain nerve-cells is severed, and that they are thus deprived of the nutritive influence which such centers exert. Such centers are called *trophic centers*, and the cells of the anterior cornua of the cord and the ganglia on the posterior roots of the spinal nerves are familiar illustrations. That these are true trophic centers for nerves seems to be beyond dispute, but this is an entirely different question from that which deals with trophic nerves as regulating the nutrition of tissues other than nerves. About the existence of such nerves there is considerable doubt.

**Other Centers.**—Some writers describe a center for *erection of the penis*, and locate it in the lumbar enlargement. The afferent nerves from the penis cause this center to send out efferent impulses by which the blood-vessels are dilated and the muscles are compressed, thus preventing the return of the venous blood from the penis and bringing about erection. A center for *parturition* is described as being located in the lumbar region of the cord, above the centers already mentioned; under the influence of this the muscular tissue of the uterus contracts at the proper time and expels the fetus. Other reflex centers are described, but the tendency to extend the number of such centers seems to be beyond what the actual facts warrant. However, enough has been said to show the great importance of the spinal cord as a nervous center, independently of its function as a conductor of nervous impulses to and from the brain.

**Functions of Spinal Nerves.**—Stimulation of an anterior root causes contraction in the muscle to which it is distributed, while its division is followed by a loss of motion in the same muscle. In neither instance is sensation affected. If after the division the distal portion of the nerve is stimulated, muscular contraction will follow, while stimulation of the proximal end, that which is in connection with the cord, will produce no effect. The anterior roots are therefore efferent and motor, and are distributed to muscles.

Stimulation of a posterior root causes a sensation of pain in the part to which the nerve is distributed. Division of the root causes a loss of sensation in that part. If after division the



distal portion of the nerve is stimulated, no effect is produced, while stimulation of the proximal portion produces sensation. The posterior roots are therefore afferent and sensory and are distributed to the skin. The two roots uniting form a mixed nerve—that is, one in which there are both motor and sensory fibers.

**Recurrent Sensibility.**—When the distal end of a divided anterior root is stimulated, besides the muscular contraction which follows there is also some pain produced. If the trunk of the nerve beyond the ganglion is divided, and then the anterior root is stimulated, no muscular contraction results, but the pain is felt as before. If, however, the posterior root is divided, no sensation is produced. The sensation experienced when the anterior root is stimulated is accounted for by the presence in this root of some sensory fibers which pass up into it for a short distance and form a loop, returning to the junction of the two roots, and then pursuing their course in the posterior root. These are called *recurrent sensory fibers*. The impulse passes along these fibers to the point of junction of the two roots, and then along the posterior root to the nerve-center.

**Function of the Spinal Ganglia.**—As has already been stated, upon each posterior root of a spinal nerve, with one exception, is a ganglion. When examined under the microscope, the root-fibers spread out, passing between groups of large cells having prominent nuclei and a diameter of about 100  $\mu$ . With one of these ganglion-cells a root-fiber is in communication, and the function of these cells is to form the fibers and to regulate their nutrition; they are true trophic centers.

## THE BRAIN.

The *brain*, or *encephalon* (Figs. 278, 279), is that part of the cerebrospinal axis situated within the cranium or skull. Its divisions are sometimes described as the *forebrain*, including the hemispheres, with the olfactory lobe, the corpora striata, and the optic thalami; the *midbrain*, being the corpora quadrigemina and the crura cerebri; and the *hindbrain*—that is, the cerebellum, the pons Varolii, and the medulla oblongata.

In the adult male the brain weighs, on an average, 1415 grams; its weight in the female is about 1245 grams. In 278 cases of males in which the brain was weighed the maximum was 1841 grams and the minimum 963 grams. In 191 cases of females the maximum was 1586 grams and the minimum 878 grams. The brain of Cuvier, the great naturalist, weighed 1815 grams; that of an idiot weighed 651 grams. The brain of a mulatto not remarkable for intelligence weighed 1927 grams. The forebrain weighs about 1245 grams in the adult male.

The gray matter of the brain is in some parts on the surface,



as in the convolutions of the cerebrum; in other parts it is deeply situated, as in the basal ganglia—*i. e.*, the corpora striata, optic thalami, etc. (p. 499); while in still other parts it is scattered about without any fixed arrangement, as in the pons Varolii. The white matter is made up of fibers which come from the spinal cord; of fibers having their origin in the gray matter, and which, escaping from the skull, go to their points of distribution as the

FIG. 278.—Base of brain: 1, 2, 3, cerebrum; 4 and 5, longitudinal fissure; 6, fissure of Sylvius; 7, anterior perforated spaces; 8, infundibulum; 9, corpora albicantia; 10, posterior perforated space; 11, crura cerebri; 12, pons Varolii; 13, junction of spinal cord and medulla oblongata; 14, anterior pyramid; 14<sup>x</sup>, decussation of anterior pyramid; 15, olivary body; 16, restiform body; 17, cerebellum; 18, crura cerebelli; 21, olfactory sulcus; 22, olfactory tract; 23, olfactory bulbs; 24, optic commissure; 25, motor oculi nerve; 26, patheticus nerve; 27, trigeminus nerve; 28, abducens nerve; 29, facial nerve; 30, auditory nerve; 31, glossopharyngeal nerve; 32, pneumogastric nerve; 33, spinal accessory nerve; 34, hypoglossal nerve.

cranial nerves; and of still other fibers connecting the ganglia with one another, forming commissures.

**The Medulla Oblongata.**—The medulla oblongata, or *bulb*, is the continuation of the spinal cord, and is about 2.5 cm. long, 2 cm. broad, and 1.2 cm. thick. It is composed of gray and white matter. The gray matter, which in the cord has the characteristic double crescentic shape, approaches more and more the posterior surface

of the cord as the region of the medulla is reached, and the posterior cornua become more and more external, the whole mass of gray matter flattening out, until in the medulla it forms a layer the outer portions of which represent the posterior horns and the middle portions the anterior. The posterior columns separate in the medulla, the central canal coming to the surface posteriorly and ending in the fourth ventricle, the floor of which is the gray matter above referred to, which is, however, not limited to this site, but is present also about the aqueduct of Sylvius. From this gray matter arise all the cranial nerves excepting the olfactory and optic.

The medulla, like the cord, has an anterior and a posterior median fissure. At the lower part of the anterior fissure are fibers that cross from side to side, the decussation of the anterior pyramids. The posterior fissure of the cord widens out and forms the fourth ventricle. Some of the cranial nerves come out from the medulla, and serve as boundaries to describe the different portions of the medulla. That portion of white matter between the anterior median fissure and the roots of the hypoglossal nerve is the anterior pyramid. The lateral column is between the roots of the hypoglossal and those of the glossopharyngeal, the pneumogastric, and the spinal accessory. At the upper portion the olivary body lies between the column and the pyramid. The posterior column is between the lateral column or tract and the posterior median fissure. It is composed of three smaller columns separated by shallow grooves, the most external being the funiculus of Rolando, next the funiculus cuneatus, and the most internal the funiculus gracilis, the first two being joined in the upper part of the medulla to form the restiform body. The outer portion of the pyramid is derived

FIG. 279.—View, from below, of the connection of the principal nerves with the brain: I', the right olfactory tract; II, the left optic nerve; II', the right optic tract (the left tract is seen passing back into *i* and *e*, the internal and external corpora geniculata); III, the left oculomotor nerve; IV, the trochlear; V, V, the large roots of the trifacial nerves; + +, the lesser roots (the + of the right side is placed on the Gasserian ganglion); 1, the ophthalmic; 2, the superior maxillary; and 3, the inferior maxillary divisions; VI, the left abducens nerve; VII, VIII, the facial and auditory nerves; IX, XI, the glossopharyngeal, pneumogastric, and spinal accessory nerves; XII, the right hypoglossal nerve; C<sub>1</sub>, the left suboccipital or first cervical nerve (Nancréde)

from the direct pyramidal tracts of the same side, while the decussation consists of the fibers of the crossed pyramidal tract of the lateral column.

In the restiform bodies are to be found, besides the funiculus of Rolando and the funiculus cuneatus, fibers of the direct cerebellar tract of the lateral column. These bodies form the inferior peduncles of the cerebellum. The funiculus of Rolando is the enlarged head of the posterior cornu of the cord, and is therefore gray matter. The funiculus cuneatus is the continuation of Burdach's column of the cord, and the funiculus gracilis is the continuation of Goll's column.

**Functions of the Medulla Oblongata.**—*Conduction.*—All the impulses, whether afferent or efferent, passing between the brain and the cord must pass through the medulla.

*Nerve-centers.*—Experiments have demonstrated that all the brain above the medulla and all the spinal cord may be removed and yet life be maintained, provided that the origin of the phrenic nerves is left intact; while if all these structures are undisturbed and the medulla is destroyed, death will result. The centers in the medulla are both reflex and automatic.

*Reflex Centers.*—One of the most important of these centers is that which presides over *deglutition*. As has been seen in discussing this process, the first stage of the act is voluntary; but as soon as the food has passed into the pharynx, the act becomes involuntary. The mucous membrane of the pharynx is stimulated by the food, and the afferent fibers of the glossopharyngeal transmit the impulse to the medulla, in which a motor impulse is generated, and out along the efferent fibers comes the impulse to the constrictors of the pharynx. Centers for *vomiting*, *coughing*, *sucking*, and for other movements are described.

The act of vomiting is a reflex one, in which the fibers of the pneumogastric serve as afferent fibers, the impulses stimulating the center in the medulla, from which emanate motor impulses to the respiratory and other muscles concerned in the act. If the act of vomiting is brought on by stimulating the pharynx with a feather or with a finger, the glossopharyngeal is the carrier of the afferent impulses. Afferent impulses producing vomiting may also come from other organs, such as the kidneys, or the testicles when injured.

*Central Vomiting.*—In central vomiting the center is stimulated by impulses which come from the cerebrum.

*Merycism, or Rumination.*—The power to ruminate, by virtue of which animals chew the cud, is possessed by some human individuals, who can regurgitate the food whenever they feel so disposed, and chew it again.

*Automatic Centers.*—Besides reflex centers, which require a stimulus from without to bring them into action, the medulla

possesses automatic centers which generate and emit impulses independently of stimuli from without.

*Respiratory Center.*—This center is situated in the floor of the fourth ventricle, and when injured, respiration ceases immediately. Some authorities place it among the reflex centers. It may, indeed, be excited reflexly, but there are reasons for believing it to possess automatic powers as well. If the spinal cord is divided below the medulla, although the respiratory movements of the thorax cease, those of the nose and larynx continue. Under these circumstances no afferent impulses can be transmitted through the spinal nerves, and the only channel is the cranial nerves; but if, while the medulla and cord are left undisturbed, the cranial nerves are cut, respiration continues. These two series of experiments show that respiration will continue independently of stimuli from without—that is, automatically.

The principal nerves that transmit the efferent impulses producing the respiratory movements are the intercostals to the intercostal muscles, and the phrenics to the diaphragm. The respiratory center is double, so that one side may act after the other is injured. Division of one phrenic paralyzes only the side of the diaphragm to which it is distributed. The respiratory center may also be excited reflexly. The afferent fibers under these circumstances are those of the pneumogastric.

*Cardio-inhibitory Center.*—In the cardio-inhibitory center are generated those impulses which, travelling to the heart by the vagus nerve, inhibit or restrain the action of that organ. These fibers convey impulses to the heart and to the muscular fibers of the superior vena cava, some of which diminish the frequency of the heart's action, while others lessen the strength of its contractions. This center can be stimulated directly, as when the blood is very venous or when the blood-pressure in the cerebral arteries is increased. It may also be stimulated reflexly, as when the sensory nerves of the abdominal viscera are irritated, as is shown in Goltz's percussion experiment, by percussion of the abdomen of a frog.

*Cardio-accelerator Center.*—Fibers from this center, whose existence is not absolutely demonstrated, convey impulses to the heart which increase the frequency of its beats, and there are also fibers which transmit impulses that increase the force of the systole. These fibers pass down the spinal cord and thence into the sympathetic through the communicating branches of the inferior cervical and the six upper thoracic nerves.

*Vasomotor Center.*—The principal vasomotor center is situated in the medulla, in the floor of the fourth ventricle, extending from its upper part to a point about 4 mm. from the calamus scriptorius. When the center is destroyed there is a marked fall in arterial blood-pressure, due to the loss of tone in the small blood-vessels. After a while the pressure is increased under the influence of stimuli sent out from the subsidiary vasomotor centers in the cord.

When the center is stimulated, arterial pressure is increased on account of the constriction of the vessels.

*Vasomotor Nerves.*—The vasomotor nerves, which originate in the cells of the vasomotor center in the bulb, pass down the lateral column of the spinal cord, and it is believed that they arborize around the cells of the subsidiary centers in the spinal cord, although the precise location of these centers has not been determined. The cells in these subsidiary centers give rise to axis-cylinders which form a part of medullated nerve-fibers that enter as component parts of the anterior roots of the spinal nerves.

*Vasoconstrictor Nerves.*—These nerves carry impulses which cause constriction of the arterioles. They pass out from the cord in the anterior roots of the spinal nerves from the second thoracic to the second lumbar, which they leave by the white *rami communicantes*, passing into the sympathetic ganglia situated along the vertebral column. These ganglia contain cells around which the nerve-fibers arborize, and they are spoken of as *cell stations*. From these cells axis-cylinder processes are given off which are continued as non-medullated fibers and which carry the impulses that originate in the vasomotor centers.

*Vasodilator Nerves.*—The description of the vasoconstrictor fibers just given applies in general to the vasodilator, though there are some marked exceptions, for while, as a rule, they pass out together, still some do not. A striking example of this is the chorda tympani, which is given off from the facial. Nor do the dilator nerves arborize around the cells of the ganglia of the sympathetic chain, but pass through these and lose their medullary sheaths in the collateral ganglia, such as the semilunar, around whose cells they arborize.

*Depressor Nerve-fibers.*—Between the heart and the medulla are nerve-fibers which carry impulses from the heart to the vasomotor nerve-center, which impulses inhibit the center, and thus diminish the impulses to the muscular coat of the arteries, thereby causing the arteries to dilate and reducing arterial pressure. In the rabbit these fibers are together and form the depressor nerve, but in most animals they are joined with the fibers of the pneumogastric. By means of these fibers the nerve-center can be inhibited and arterial pressure lessened, thus reducing the work of the heart.

*Pons Varolii.*—The pons Varolii (tuber annulare or mesocephalon) is situated just above the medulla, and is composed of three sets of fibers and of some gray matter. The first set consists of superficial transverse fibers which cross the upper part of the medulla and connect the two hemispheres of the cerebellum, forming at the sides the crura cerebelli or middle peduncles. The second is made up of longitudinal fibers which come from the pyramids of the medulla and pass on to help form the crura cerebri. The third set is also transverse and is deeply

situated, connecting the middle peduncles of the cerebellum. Among its fibers are collections of gray matter.

*Functions of the Pons Varolii.*—The anatomic relations of the pons show that it must serve as a conductor of impulses both to and from the centers above. As to the function of its gray matter, comparatively little is known, save that from a portion of it some of the cranial nerves arise. If it is stimulated or divided, pain and spasms are produced. When a lesion is situated in the lower half of the pons, there result facial paralysis on the same side as the lesion, and motor and sensory paralysis on the opposite side of the body. This is called alternate paralysis. If the lesion is in the upper half of the pons, the facial paralysis and that of the body are on the same side. When the pons is suddenly and extensively injured, a condition of hyperpyrexia is often produced, the temperature rising rapidly within an hour. This is probably

s cell.

late  
anular

r

FIG. 280.—Section through the human cerebellar cortex vertical to the surface of the convolution; treatment with Müller's fluid,  $\times 115$  (Böhm and Davidoff).

due to the influence of the gray matter in the floor of the fourth ventricle, or possibly to the involvement of some special heat-regulating center.

Stellate cell.

Large stellate cell.

Neuraxis of cell of granular layer

Telodendron of collaterals of climbing fiber.

Stellate cell

Molecular layer

Granular layer

Medulla layer

A. Neuraxis of Purkinje's cell. Moss-fiber. Cell of granular layer. B. Neuraxis of cell of granular layer. C. Climbing fiber.

FIG. 281.---Schematic diagram of the cerebellar cortex: A, by ordinary nuclear staining (omitting the layer of Purkinje's cells); B, vertical to the surface of the convolution; C, longitudinal section through the convolution; B and C, by the chrome-silver method (Böhm and Davidoff).

**The Cerebellum.**—The cerebellum (Figs. 280, 281) is composed externally of gray matter, which also penetrates into the substance of the organ, forming with the white matter the *laminae*. In the central part of the cerebellum is white matter, in which is imbedded a collection of gray matter, the *corpus dentatum*. The cerebellum is connected with the rest of the encephalon by the superior, the middle, and the inferior peduncles. The superior peduncles (*processus e cerebello ad testes*) connect the cerebellum with the cerebrum; the middle peduncles (*crura cerebelli*) connect the two cerebellar hemispheres; the inferior (*processus ad medullam*) connect the cerebellum and medulla oblongata.

The gray matter consists of two layers, an *inner* or *granular layer*, composed of nerve-cells, principally small in size, and neuroglia; and an *outer* or *molecular layer*, composed of fine nerve-fibers and nerve-cells. Between these two layers are the *cells of Purkinje*, which are flask-shaped, and from the base of each of which is given off a neuron, which is continued as an axis-cylinder

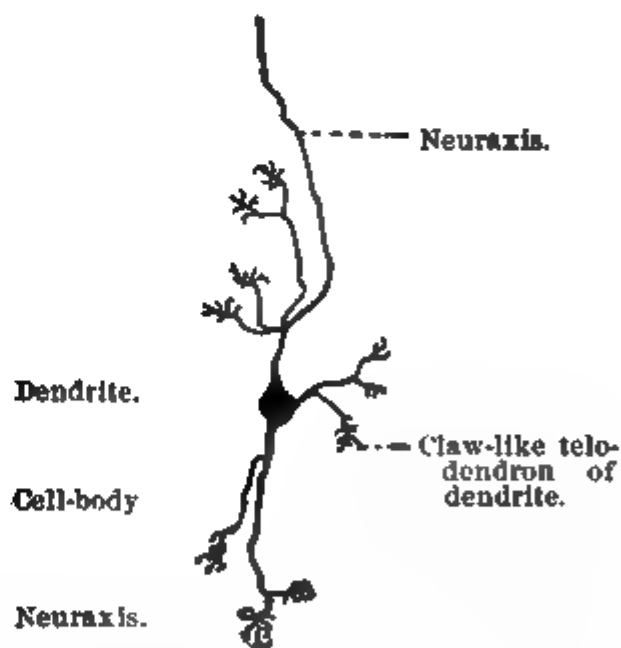


FIG. 282.—Cell of Purkinje from the human cerebellar cortex; chrome-silver method;  $\times 120$  (Böhm and Davidoff).

FIG. 283.—Granular cell from the granular layer of the human cerebellar cortex; chrome-silver method;  $\times 100$  (Böhm and Davidoff).

of a medullated nerve-fiber of the white center. From the opposite side are given off dendrons which pass into the gray matter. In discussing the structure of the cerebellum, Schäfer says: "The dendrons of the cells of Purkinje spread out in planes transverse to the lamellæ of the organ, so that they present a different appearance according to whether the section is taken across the



lamellæ or along them. These dendrons are invested at their attachment to the cell, and to some extent along their branchings, by basketworks formed by the terminal arborizations of certain fibers of the medullary center. The body of the cell of Purkinje is further invested by a feltwork of fibrils formed by the arborization of axis-cylinder processes of the same nerve-cells in the outer layer of the gray matter. Each cell has therefore a double investment of this nature, one covering the dendrons, the other the body of the cell. Ramifying among the granule-layer are peculiar fibers derived from the white center, and characterized by having pencils of fine short branches at intervals like tufts of moss. These are termed by Cajal the *moss-fibers*; they end partly in the granule-layer, partly in the molecular layer."

**Functions of the Cerebellum.**—If the surface of the cerebellum is irritated, no muscular movements are produced, nor is there any evidence of sensation; if, however, the irritation is applied near the medulla or inferior peduncles, both pain and muscular contraction result. If the cerebellum is removed wholly or partially, sensation is not diminished in the part of the body below, nor is there any impairment of the power of producing muscular movements, nor of the special senses, nor of the intelligence; but there is a marked want of harmony in the muscular movements—a lack of co-ordination. Attention has already been called to the fact that even the simplest movements that are made require the harmonious action of different muscles, and when these movements are more complex, they require different sets of muscles. If these movements do not occur at just the right time and are not produced in the right manner, the result is disorder instead of harmony; or, as it is expressed, there is a want of co-ordination, or a condition of *inco-ordination* or *cerebellar ataxy*. This is the effect of removing the cerebellum. Thus, if the cerebellum of a pigeon is removed, and an attempt is then made by it to fly, it is unsuccessful, for this act requires the consentaneous action of both wings, which action is absent. In walking the bird reels like a person intoxicated, and cannot go to the spot for which it apparently set out. It should be borne in mind that there is no paralysis either of motion or of sensation in this condition, but the voluntary movements which originate in the cerebrum, and which are in the normal condition co-ordinated by the cerebellum, pass to the muscles without this regulating influence, and the result is a series of disordered movements.

Especially marked is this inco-ordination in connection with the maintenance of the equilibrium of the body and locomotion. Indeed, some authorities are inclined to limit the functions of the cerebellum to this, and to regard it as not being the controlling organ of co-ordination in general, quoting experiments upon animals in which, after the first effects of its removal had passed away, there was a return of the co-ordinating power,

and also instances in the human subject in which during life the movements had been co-ordinated, yet after death the cerebellum had been found completely disorganized.

It is interesting to know that in animals that produce complex movements the cerebellum is considerably developed, while in those whose movements are simple, such as the frog, this organ is exceedingly small.

**Sources of Impressions that reach the Cerebellum.**—The anatomic relations of the cerebellum are so intimate that impressions of many kinds can reach it and thus enable it to preside over this most important function of co-ordination, especially as regards equilibration and locomotion.

**Equilibration.**—Sewall defines equilibrium as “a state in which all the skeletal muscles are under control of nerve-centers, so that they combine, when required, to resist the effect of gravity or to execute some co-ordinated motion.” In order that these centers may send to the muscles of the body impulses that are adapted to produce the desired result, it is absolutely essential that they should receive impressions which will give them cognizance of the exact position of the body and of the condition of the muscles at the moment as to contraction or relaxation. These impressions or sensations taken as a whole constitute the *sense of equilibrium*, and while it is doubtless true that all sensations contribute to bring about this result, yet there are some which are more directly concerned than others. These are impulses received from the skin, from the muscles, and from the semicircular canals, the last being doubtless the most important.

**Impressions from the Semicircular Canals.**—These are sometimes described under the name *labyrinthine impressions*. For a description of the labyrinth, the reader is referred to page 607.

Although in intimate anatomic relationship with the organs of hearing, there is still no doubt that the semicircular canals bear no physiologic relationship with that special sense, for removal of these structures leaves hearing unimpaired, provided, of course, the cochleæ are uninjured. On the other hand, serious disturbances of equilibrium do result, and these vary according as one or another of the canals is destroyed. Thus, if in a pigeon the horizontal canal is destroyed, the bird moves its head from side to side around a vertical axis: whereas if the injury is to the superior canal, the movements are vertical around a horizontal axis. When a pigeon whose semicircular canals have been injured is in a resting posture, it stands with its head turned backward or forward or to one side, never in a natural position; and when disturbed, its movements are irregular, accompanied by rolling of the eyes and an inability to fly. If the injury is limited to one side, recovery soon takes place; while if the canals on both sides are destroyed, the condition is a more persistent one. Different animals act somewhat differently after injury to the canals; in mam-

mals the movements described affect the eyes rather than the head.

The explanation of the manner in which the canals are concerned with equilibrium is that any change in the pressure of the endolymph upon the hair-cells of the *cristæ acusticæ* in the ampullæ of the semicircular canals will produce a change in the sensations which reach the center presiding over equilibration—*i. e.*, probably the middle lobe of the cerebellum.

It will be seen by a reference to Fig. 284 that the canals are

FIG. 284.—Diagram of semicircular canals to show their positions in three planes at right angles to one another. It will be seen that the two horizontal canals (H) lie in the same plane, and that the superior vertical of one side (S) lies in a plane parallel to that of the posterior vertical (P) of the other (after Ewald).

at right angles to one another and thus occupy the three planes of space: the horizontal canal of one side being in the same plane with the corresponding canal of the other, and one anterior vertical canal practically parallel with the opposite posterior vertical canal. Thus movements of the head cause an increase of the pressure of the endolymph in one ampulla and a decrease

in that of its parallel canal on the other side, and the sensory impressions thus produced are at once transmitted to the center. When a canal is injured, its endolymph is drained off, and at once there is an interference with the pressure upon the hair-cells, together with a consequent modification of the normal impressions.

FIG. 285.—Diagrammatic horizontal section through the head to illustrate the planes occupied by the semicircular canals: S, superior canal; P, posterior canal; H, horizontal canal (after Waller).

Observation upon man confirms these experiments upon the lower animals. Thus a man with his eyes closed lying upon a table which is rotated, can tell that he is being

moved, in what direction, and to some extent through how great an angle; and when the rotation ceases the sensation of rotation in the opposite direction is experienced. In deaf-mutes, in whom

this condition is due to a defect in the internal ear, there is an absence of the dizziness experienced by normal individuals when rapidly rotated in a swing. The vertigo of *Ménière's disease* is accompanied by changes in the internal ear. It has also been observed that defects of locomotion and equilibration are more common in deaf and dumb children than in those that are normal.

*Static Equilibrium.*—By this term is meant the *equilibrium of rest*, and Lee regards the utricle and saccule as being the organs concerned in this function. That is, that the knowledge of the position of the head while at rest is communicated to the co-ordinating center in the cerebellum by the pressure of the endo-

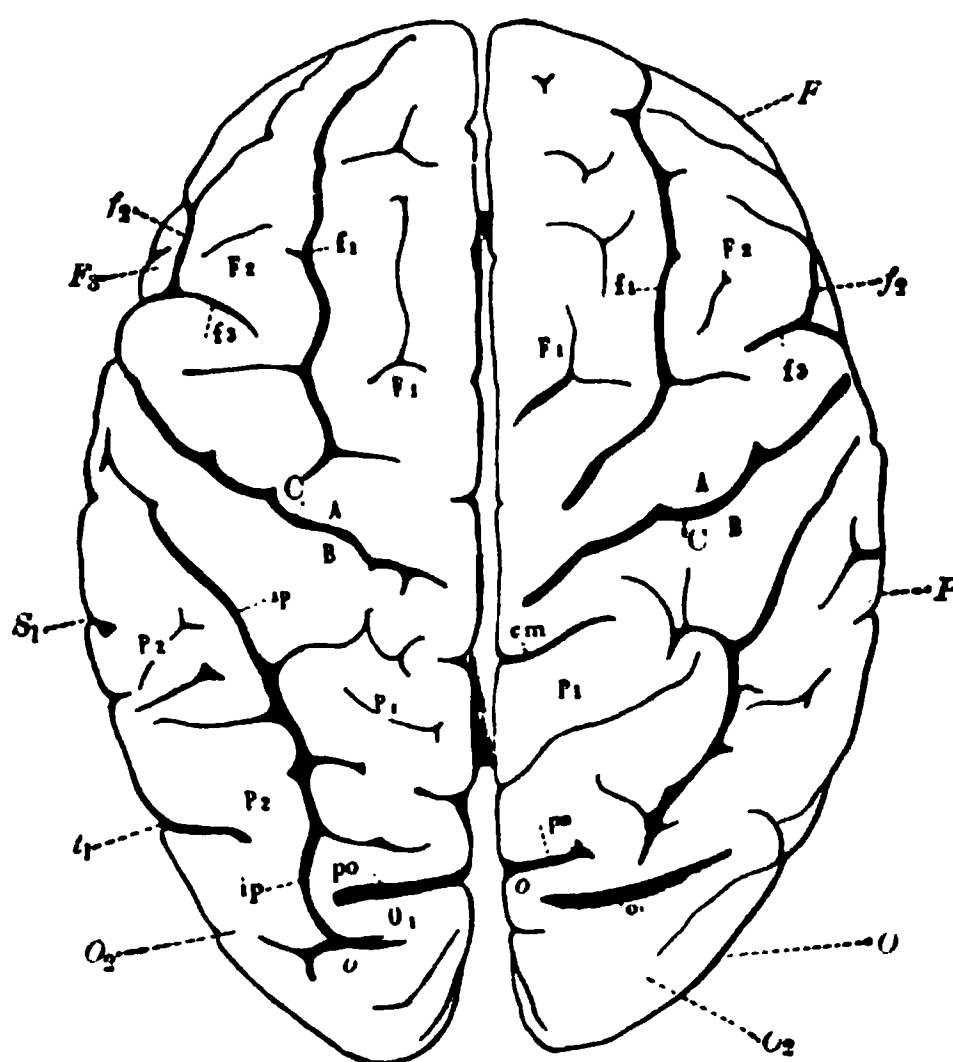


FIG. 286.—View of the brain from above: A, anterior central or ascending frontal convolution; B, posterior central or ascending parietal convolution; C, central fissure, or fissure of Rolando; cm, callosomarginal sulcus; F, frontal lobe; F<sub>1</sub>, upper, F<sub>2</sub>, middle, F<sub>3</sub>, lower frontal convolution; f<sub>1</sub>, superior frontal sulcus; f<sub>2</sub>, inferior frontal sulcus; f<sub>3</sub>, vertical fissure (sulcus præcentralis); ip, interparietal sulcus; O, occipital lobe; o, sulcus occipitalis transversus; O<sub>1</sub>, first occipital convolution; O<sub>2</sub>, second occipital convolution; P, parietal lobe; po, parieto-occipital fissure; P<sub>1</sub>, upper or posteroparietal lobule; P<sub>2</sub>, lower parietal lobule, constituted by P<sub>2</sub>, gyrus supramarginalis; P<sub>2</sub>', gyrus angularis; S<sub>1</sub>, end of the horizontal branch of the fissura Sylvii; t<sub>1</sub>, upper temporal fissure.

lymph upon the otoliths, and these in turn upon the hair-cells of the maculæ acusticæ.

*Dynamic Equilibrium.*—This is the *equilibrium of motion*, and, as already stated, is presided over by the semicircular canals, from which impressions pass to the cerebellum.

**The Cerebrum.**—The cerebrum, which in man makes up about four-fifths of the encephalon, is divided into two hemispheres which are separated by the great longitudinal fissure (Figs. 286–289), but are connected by a white commissure, the *corpus*

*callosum*. The surface presents depressions, *fissures* and *sulci*, and prominences, *convolutions* or *gyri*. The external portion of the hemispheres is gray nervous matter about 3 mm. in thickness, beneath which is white matter. The fissures are not numerous, but are quite constant; they are folds of the brain-matter both gray and white. The sulci are depressions of the gray matter alone; they are very numerous and inconstant. As gray matter is present on both sides of the fissures and sulci, this arrangement permits of a larger amount of gray matter than could exist were it only upon the surface of the convolutions. In a brain, therefore, where the sulci are deep and numerous the amount of gray matter

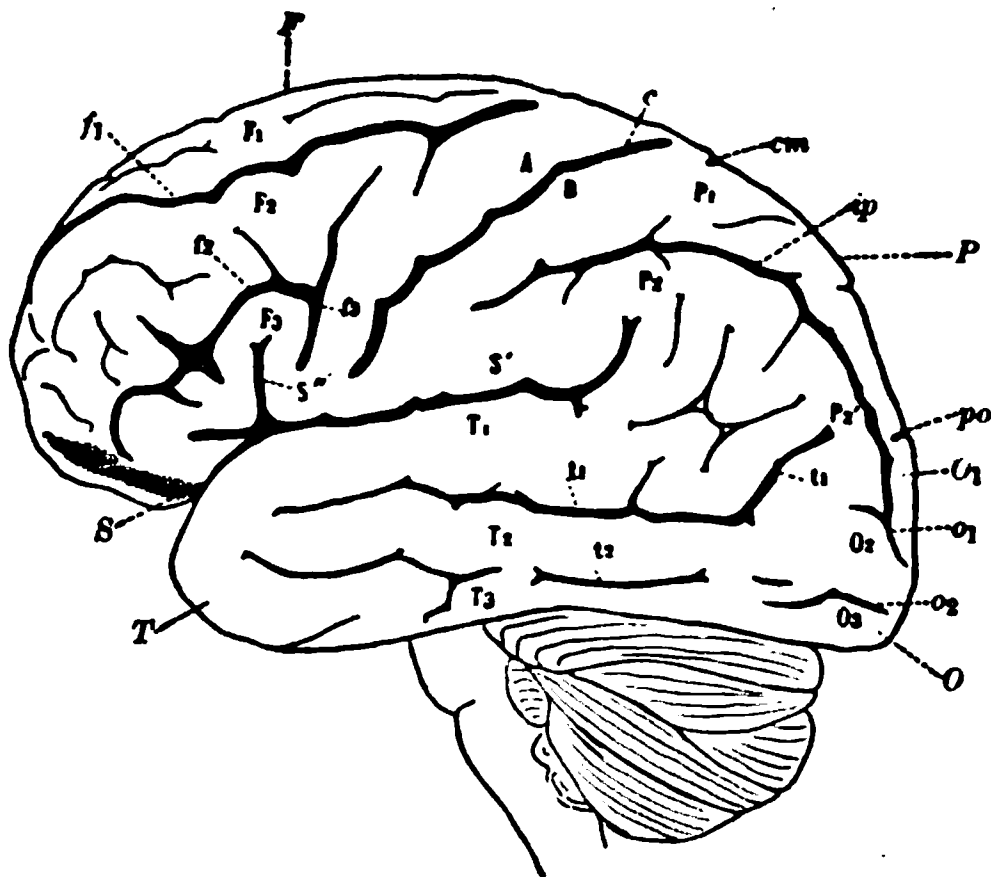


FIG. 287.—Outer surface of the left hemisphere: *A*, anterior central or ascending frontal convolution; *B*, posterior central or ascending parietal convolution; *c*, sulcus centralis or fissure of Rolando; *cm*, termination of the callosomarginal fissure; *F*, frontal lobe; *F*<sub>1</sub>, superior, *F*<sub>2</sub>, middle, and *F*<sub>3</sub>, inferior frontal convolution; *f*<sub>1</sub>, superior, and *f*<sub>2</sub>, inferior frontal sulcus; *f*<sub>3</sub>, sulcus præcentralis; *ip*, sulcus intraparietalis; *O*, occipital lobe; *O*<sub>1</sub>, first, *O*<sub>2</sub>, second, *O*<sub>3</sub>, third occipital convolutions; *o*<sub>1</sub>, sulcus occipitalis transversus; *o*<sub>2</sub>, sulcus occipitalis longitudinalis inferior; *P*, parietal lobe; *po*, parieto-occipital fissure; *P*<sub>1</sub>, superior parietal or posteroparietal lobule; *P*<sub>2</sub>, inferior parietal lobule, viz., *P*<sub>2</sub>, gyrus supramarginalis; *P*<sub>2</sub>', gyrus angularis; *S*, fissure of Sylvius; *S'*, horizontal, *S''*, ascending ramus of the same; *T*, temporosphenoidal lobe; *T*<sub>1</sub>, first, *T*<sub>2</sub>, second, *T*<sub>3</sub>, third temporosphenoidal convolutions; *t*<sub>1</sub>, first, *t*<sub>2</sub>, second temporosphenoidal fissures.

exceeds that in a brain where they are more shallow and less abundant. This gray matter is the *cortical substance*.

**Fissures of the Cerebrum.**—The fissures serve as landmarks in the description of the different parts of the hemispheres. Besides the great longitudinal fissure, there are (1) the fissure of Sylvius; (2) that of Rolando; and (3) the parieto-occipital fissure. These fissures divide each hemisphere into 5 lobes.

(1) The *fissure of Sylvius* is, next to the great longitudinal fissure, the most important. It is found in all animals whose brains have any fissures. It exists in the human brain in the

third month of intra-uterine life. It commences at the base of the brain, and runs outward, backward, and upward, giving off a short anterior branch or limb. The continuation of the fissure backward from where this branch is given off is the *posterior branch* or horizontal limb, which ends in the parietal lobe. The fissure of Sylvius is the boundary between the frontal and parietal lobes on the one hand and the temporosphenoidal on the other. At the middle and anterior part of this fissure, deeply situated, is the island of Reil, or insula, or central lobe.

(2) The *fissure of Rolando* starts near the median line, and runs downward and forward nearly to the fissure of Sylvius. It is the boundary between the frontal and parietal lobes.

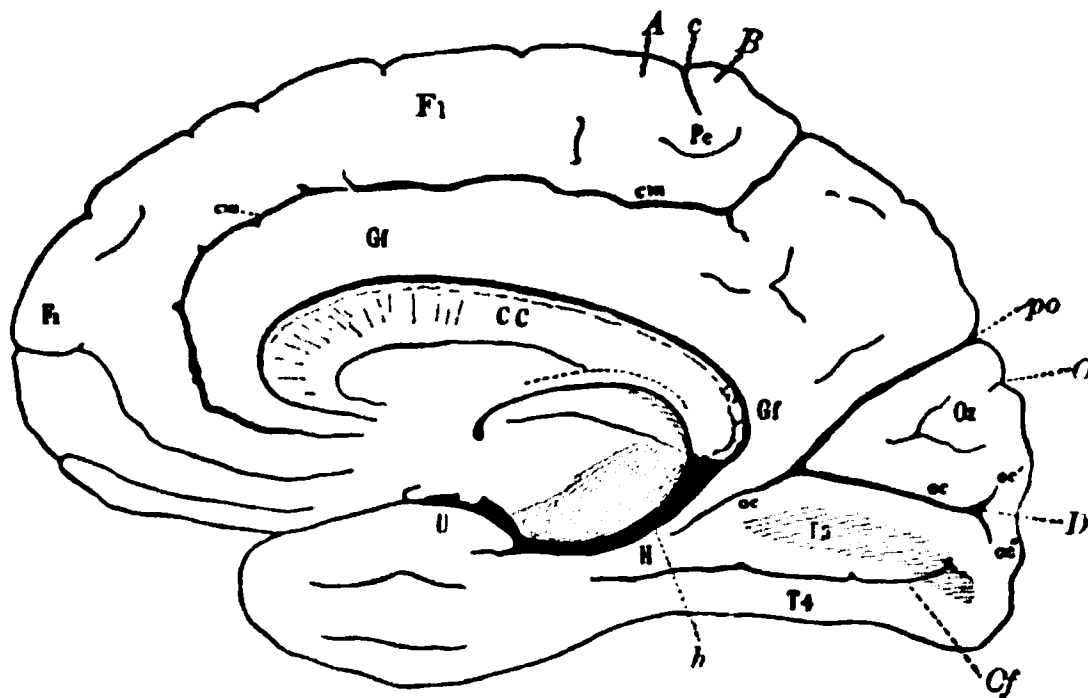


FIG. 288.—Inner surface of right hemisphere: *A*, ascending frontal; *B*, ascending parietal convolution; *c*, terminal portion of the sulcus centralis, or fissure of Rolando; *Cc*, corpus callosum, longitudinally divided; *Cf*, collateral or occipito-temporal fissure (Ecker); *cm*, sulcus callosomarginalis; *D*, gyrus descendens; *F1*, median aspect of the first frontal convolution; *Gf*, gyrus fornicatus; *H*, gyrus hippocampi; *h*, sulcus hippocampi, or dentate fissure; *O*, sulcus occipitalis transversus; *oc*, calcarine fissure; *oc'*, superior, *oc''*, inferior ramus of the same; *Oz*, cuneus; *po*, parieto-occipital fissure; *Pi''*, precuneus; *T4*, gyrus occipitotemporalis lateralis (lobulus fusiformis); *Tb*, gyrus occipitotemporalis medialis (lobulus lingualis); *U*, uncinate gyrus.

(3) The *parieto-occipital fissure* is about half-way between the fissure of Rolando and the posterior extremity of the brain, and is the boundary between the parietal and occipital lobes.

**Lobes of the Cerebrum.**—The lobes of the cerebrum are (1) the frontal, (2) the parietal, (3) the occipital, (4) the temporosphenoidal, and (5) the central, or island of Reil.

(1) The *frontal lobe* is above the fissure of Sylvius and in front of the fissure of Rolando. It is divided into 4 convolutions by 3 sulci, or fissures as they are sometimes called. The precentral fissure or sulcus is in front of the fissure of Rolando, and the convolution between the two is the ascending frontal. From the upper extremity of this sulcus the superior frontal sulcus runs downward and forward between the superior and middle frontal

convolutions, while from the lower extremity extends the inferior frontal sulcus, separating the middle and inferior frontal convolutions. Thus the frontal lobe is divided into the ascending, superior, middle, and inferior frontal convolutions.

(2) The *parietal lobe* is behind the frontal and in front of the occipital lobe, the fissure of Rolando being its anterior, and the parieto-occipital fissure its posterior boundary. Its inferior boundary is the fissure of Sylvius and the imaginary continuation of it to the superior occipital sulcus. It has 2 sulci, the intra-parietal and the post-central, and 3 convolutions, the ascending, superior, and inferior parietal.

(3) The *occipital lobe* is posterior to the parietal, and has 2

*Lobulus paracentralis.*

FIG. 289.—Lateral view of the brain: gyri and lobuli marked with antique type, the sulci and fissures with italic type (combined from Ecker).

sulci, the superior and middle, and 3 convolutions, the superior, middle, and inferior occipital, the latter being subdivided into the supramarginal and the angular.

(4) *The Temporosphenoidal Lobe.*—The fissure of Sylvius forms the anterior and superior boundaries of this lobe, while its posterior boundary is the imaginary continuation of the occipitoparietal fissure. It presents 2 sulci, the superior temporosphenoidal or parallel, and the middle temporosphenoidal. Its convolutions are 3, the superior, middle, and inferior temporosphenoidal.

(5) The *central lobe*, or *island of Reil*, is situated at the base of the brain, in the fissure of Sylvius. It consists of 6 convolutions, the *gyri operi*.



*Crura cerebri*, also called the *peduncles of the cerebrum*, are made up of white matter, nerves which are continuous with those already studied in the medulla and pons, together with nerves from the cerebellum, the superior peduncles. Between the superficial fibers of the crura, the *crusta*, and the deeper ones, the *tegmen*, is the *locus niger*, a collection of gray matter. The fibers of the crura on their way upward to the gray matter of the hemispheres pass through the corpora striata and the optic thalami.

**Basal Ganglia.**—At the base of the hemisphere are certain bodies, the basal ganglia, which are the corpora striata, the optic

co

7

FIG. 290.—Vertical section through the cerebrum and basal ganglia to show the relations of the latter: *co.*, cerebral convolutions; *c.c.*, corpus callosum; *v.l.*, lateral ventricle; *δ.*, fornix; *v.III.*, third ventricle; *n.c.*, caudate nucleus; *th.*, optic thalamus; *n.l.*, lenticular nucleus; *c.i.*, internal capsule; *cl.*, claustrum; *e.c.*, external capsule; *m.*, corpus mammillare; *t.o.*, optic tract; *s.t.t.*, stria terminalis; *n.a.*, nucleus amygdalæ; *cm.*, soft commissure; *co.i.*, island of Reil (Schwalbe).

thalami, the tubercula quadrigemina or corpora quadrigemina, the corpora geniculata, and the locus niger.

*Corpora striata*, with the optic thalami, are called the *cerebral ganglia*. The corpora striata present a striped appearance, which is due to a mixture of gray and white matter, the latter being bundles of fibers which have come from below and within. Although at the lowest part each corpus striatum is a single body, at the upper part it is divided into two portions, the *caudate nucleus* and *lenticular nucleus*. The lenticular nucleus, the more posterior, is separated from the optic thalamus by white matter, the *internal capsule*, which is the continuation of the crus cerebri. Outside the lenticular nucleus is white matter, the *external capsule*, beyond which is a layer of gray matter, the *claustrum*, and



external to all these structures is the *island of Reil*. The cortical substance is at this point very near the gray matter of the basal ganglia.

The fibers of the internal capsule, passing upward, radiate forward, upward, and backward, forming the *corona radiata*, the fibers of which pass to the cortex, each one being the continuation of the axis-cylinder process of a pyramidal cell. The fibers of the internal capsule give off collaterals which pass to the optic thalamus, and the nucleus caudatus and nucleus lenticularis of



FIG. 291.—Diagram to show the connection of the frontal occipital lobes with the cerebellum: *ec.*, the dotted lines passing in the crusta (*TOC*), outside the motor fibers, indicate the connection between the temporo-occipital lobe and the cerebellum; *F.C.*, the frontocerebellar fibers, which pass internally to the motor tract in the crusta; *I.F.*, fibers from the caudate nucleus to the pons, *Fr.*, frontal lobe; *Oc.*, occipital lobe; *AF.*, ascending frontal; *AP.*, ascending parietal convolutions; *PCF.*, precentral fissure in front of the ascending frontal convolution; *FR.*, fissure of Rolando; *IPF.*, interparietal fissure. A section of crus is lettered on the left side: *S.IV.*, substantia nigra; *PY.*, pyramidal motor fibers, which on the right are shown as continuous lines converging to pass through the posterior limb of *I.C.*, internal capsule (the knee or elbow of which is shown thus (\*)) upward into the hemisphere and downward through the pons to cross at the medulla in the pyramidal decussation; *lpt.*, crossed pyramidal tract; *apt.*, direct pyramidal tract (Gowers).

the corpus striatum. These ganglia give off fibers which pass into the internal capsule and corona radiata. There are, therefore, fibers passing into these ganglia and others passing out from them, the latter being the more numerous. The pyramidal fibers in their downward course thus give off collaterals which arborize around the cells of the corpus striatum and optic thalamus, and from these ganglia axis-cylinder processes pass out to form a part of the pyramidal tract. So, also, the sensory fibers, particularly those of the fillet, arborize around the cells of the optic thalamus and the subthalamie region.

It is in this locality that hemorrhage produces such serious consequences. The blood-vessels supplying the basal ganglia may rupture on account of a diseased condition, and as a result of this *apoplexy* or paralysis may occur, or the hemorrhage may prove fatal. When the hemorrhage takes place into the anterior portion of the internal capsule, *hemiplegia*, or paralysis of motion in the opposite side of the body, will result; while if it is into the posterior part, paralysis of sensation will occur on the opposite side.

*Optic Thalami* (Fig. 290).—Each of these bodies is covered by a layer of white fibers, which is especially prominent in the internal capsule. From the capsule it enters the thalamus, connecting it with the hemisphere. The gray matter of the thalamus, of which it is principally composed, is aggregated into two masses, an *outer* and an *inner nucleus*, separated by a white lamina, the *internal medullary lamina*. In the anterior portion there is a third portion of gray matter, in which the nerve-cells are quite large. The cells of the thalamus are multipolar and fusiform.

*Corpora Quadrigemina*.—These bodies, 4 in number, the anterior pair being the *testes*, and the posterior the *nates*, are situated behind the third ventricle and posterior commissure and under the posterior border of the corpus callosum. They consist principally of gray matter. Each gives off a bundle of white fibers to the corpora geniculata, which joins the optic tract of the same side, and each receives fibers of the fillet which can be traced to nuclei of the opposite funiculus gracilis and cuneatus. Thus the fillet serves as a channel for afferent impulses which have traversed the fibers of the posterior roots of the spinal nerves. These nerves arborize around the cells of the nuclei, from which the fibers of the fillet arise. Over the gray matter of the superior corpora quadrigemina is a layer of nerve-fibers which have their origin in the nerve-cells of the retina, coming by way of the optic tract, and which pass into the corpora quadrigemina and arborize around the cells of the gray matter. Schäfer says that these cells “are very various in form and size, and are disposed in several layers, which are better seen in the optic lobe of the bird (Fig. 292) than in mammals. Most of their processes pass ventralward. Their destination is not certainly known, but some appear to pass downward with the fillet, others probably turn upward and run in the tegmentum toward the higher parts of the brain; while others, perhaps most, probably form terminal arborizations around the motor cells of the oculomotor and other motor nuclei. All the nerve-fibers of the optic nerve and optic tract do not enter the corpora quadrigemina. Some pass into the lateral geniculate bodies and form arborizations there. On the other hand, from the cells of these geniculate bodies the axis-cylinder processes appear to pass to the cortex of the brain (occipital region).”

*Functions of the Cerebral Ganglia.*—A marked change has taken place within comparatively recent times as to the functions and importance of the corpora striata and the optic thalami. The former were for a long period of time considered important motor centers, and the latter as performing the same rôle with reference to sensation. This was doubtless largely due to the fact, to which Kirkes calls attention, that when a hemorrhage took place in the

A

B

FIG. 292.—Sections of optic lobe of bird taken in planes at right angles to one another (S. Ramón y Cajal) (Golgi method).

A. Anteroposterior section: a, optic fibers cut across. The other letters indicate different kinds of cells, of which it will be noticed that some have their axis-cylinder processes extending outward toward the optic fiber layer, and others have their axis-cylinder processes extending inward toward a deep layer of nerve-fibers; e, some have only short neurons ramifying in adjacent layers.

B. Transverse section: a, optic fibers cut longitudinally; b, c, d, e, their terminal ramifications in different layers of the gray matter.

region of the corpora striata, motor paralysis was the result; and that when it occurred in the region of the optic thalamus, sensory paralysis followed. It was, therefore, natural to attribute motion and sensation to these ganglia respectively. It is now known that when the hemorrhage is limited to these ganglia paralysis is slight, or even absent altogether, and that the effects of cerebral hemorrhage ordinarily observed are due to injury of the internal capsule; and hemorrhage into the anterior portion is followed by motor paralysis, because it is here that the fibers pass which carry motor impulses from the cortex to the cord; and that hemorrhage

into the posterior part is followed by paralysis of sensation, because in this part of the capsule are the fibers which carry the sensory impulses from the cord to the cortex. The cerebral ganglia are subordinate centers: the corpus striatum with regard to motion; the optic thalamus with regard to sensation, particularly to vision.

**Microscopic Structure of the Cerebrum (Figs. 293, 294).—The**



a

b

c

d

e

f

FIG. 293.—The layers of the cortical gray matter of the cerebrum (Meynert).

FIG. 294.—Schematic diagram of the cerebral cortex: a, molecular layer with superficial (tangential) fibers; b, striation of Bechtereff-Kaes; c, layer of small pyramidal cells; d, stripe of Baillarger; e, radial bundles of the medullary substance; f, layer of polymorphous cells (Böhm and Davidoff).

**Gray Matter.**—The gray matter on the external surface of the cerebrum, the *cortex*, is divisible into five layers, whose distinctness varies in different regions, being perhaps most marked in the parietal lobe; but in the posterior portion of the occipital lobe, in the gray portion of the hippocampus major, in the wall of

## VOUS SYSTEM.

the olfactory bulb this arrangement is as follows:

is the most superficial, and consists of glion-cells, and a network of non-nerve-fibers, the latter forming a plexiform layer in contact with the pia mater.

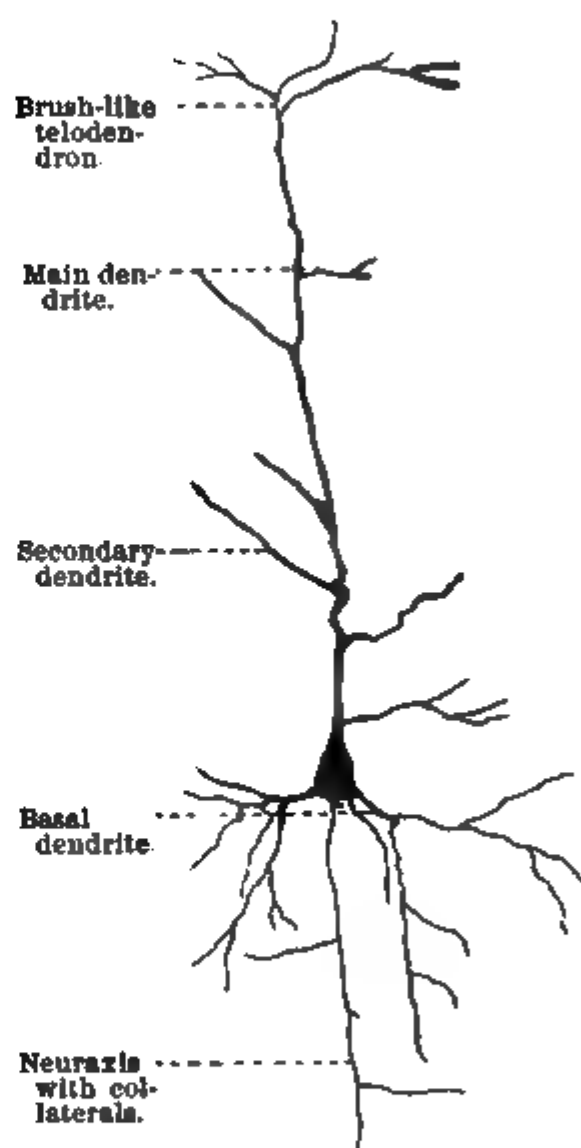


FIG. 296.—Large pyramidal cell from the human cerebral cortex; chrome-silver method;  $\times 150$  (Böhm and Davidoff).

The non-medullated fibers have their origin principally in the small pyramidal cells of the second layer, but also come from the dendrites and axis-cylinder processes of the cells of the first layer. The nerve-cells of this layer have two or three axis-cylinder processes arranged horizontally, which terminate by arborization in this superficial layer.

2. *Small Pyramid-cell Layer.*—The cells of this layer are small

and pyramidal, having a diameter of about  $10\ \mu$ , with their long axes vertical to the surface of the convolutions. Their dendrites pass into the first layer; their axis-cylinder processes passing off from the base give off collaterals and form *projection-fibers* which go to the corpus striatum.

3. *Large Pyramid-cell Layer*.—This layer is characterized by being made up of pyramidal cells larger than those of the second layer, and increasing in size from above downward, reaching a diameter of  $40\ \mu$ . The breadth of this layer is shown in the illustration. The axis-cylinder processes of these cells give off collaterals and pass into the white substance of the brain, where they become medullated.

4. *Polymorphous-cell Layer* (Fig. 295).—The cells of this layer are irregular in shape, each giving off several dendrites and an axis-cylinder process. Some of these processes pass into the white center, while others pass to the first layer and are contained in one of its fibers.

5. *Fusiform-cell Layer*.—In this layer are spindle-shaped or fusiform cells. In the inner half they are numerous and arranged parallel to the surface. The *claustrum* is made up of this layer, separated by white substance from the other gray matter.

The different varieties of cells are well shown in Fig. 297. The number of cells in the cortex has been estimated at 1,200,000,000 by Donaldson, and 9,200,000,000 by Thompson: the latter regards 159,960 of these as motor; this number would therefore represent the largest pyramidal cells or "giant-cells."

*White Matter*.—The medullated nerve-fibers of the white center are traced through the deeper layers of the gray matter. Some are continuous with the axis-cylinder processes of the pyramidal and polymorphous cells; others arborize around the

FIG. 297 — Principal types of cells in the cerebral cortex: *A*, medium-sized pyramidal cell of the second layer; *B*, large pyramidal cell of third layer; *C*, polymorphous cell of fourth layer; *D*, cell of which the axis-cylinder process is ascending; *E*, neuroglia cell; *F*, cell of the first, or molecular, layer, forming an intermediate cell-station between sensory fibers and motor cells. Notice the tangential direction of the nerve-fibers; *G*, sensory fibers from the white matter; *H*, white matter; *I*, collateral of the white matter (Ramón y Cajal).

cells of the various layers without being anatomically in connection with them. If the axis-cylinder processes of the pyramidal cells are traced, it will be found that they take various courses. Some, *commissural fibers*, pass either directly or by collaterals through the corpus callosum from one hemisphere to the other; some join *association fibers*, and pass into the gray matter of other parts of the same hemisphere as that in which they originated; while others, *projection fibers*—and this is the course particularly of those having their origin in the largest pyramidal cells—pass downward through the corona radiata, internal capsule, and pyramidal tract. The number of pyramidal fibers has been estimated at 158,222 by Blocq and Ozanoff.

The white matter of the cerebrum, consisting of medullated nerve-fibers, may then be divided into three groups:

1. Those fibers that connect the cerebrum with the medulla oblongata, pons Varolii, and spinal cord. These are the *crura cerebri* or cerebral peduncles; hence the group is described as *peduncular* or *projection fibers*. It will be remembered that the *crura cerebri* consist of the *crusta* and *tegmentum*. The fibers which come from the pyramids of the medulla and are continued through the pons aid in forming the *crusta*. To these fibers are added others which originate in the gray matter of the aqueduct of Sylvius and in the *locus niger*.

After forming the *crura cerebri* the fibers pass upward: some of them go directly to the gray matter of the cortex: these form the *corona radiata*; others go to the internal capsule, and thence to the *corpora striata*, where they terminate; while some of the others continue on, receiving fibers from these bodies, and together they assist in forming the *corona radiata*. More fibers come from the *corpora striata* than end there, so that the number of those which emerge is greater than the number of those which enter.

The *tegmentum* of the *crus* is made up of fibers from the anterior and lateral columns of the cord, the olivary body, *funiculus cuneatus*, *funiculus gracilis*, *corpora quadrigemina*, *corpora geniculata*, and the superior peduncles of the cerebellum. These fibers pass into the optic thalami, some terminating there, while others pass through. To these latter are added fibers having their origin in the optic thalami, and together they assist in forming the *corona radiata*, being traced to the cells in the cortical substance of the temporosphenoidal and occipital lobes.

2. The second group of fibers in the cerebrum consists of those which connect the hemispheres and the basal ganglia, and are the *transverse* or *commissural* fibers. They compose the corpus callosum and the anterior and posterior commissures. The fibers of the corpus callosum connect the hemispheres, being traced into the convolutions and intersecting those of the *corona radiata*. The anterior commissure connects the *corpora striata*, and then passes through these bodies into the temporosphenoidal lobe. Some of

the fibers of the posterior commissure connect the optic thalami, while some come from the tegmentum of one side, traverse the optic thalamus, and terminate in the white matter of the temporo-sphenoidal lobe of the other side.

3. The third group, *association fibers*, connect different structures in the same hemisphere; as the *short association fibers*, which connect adjacent convolutions, and the long *association fibers*, which connect more distant parts.

**Functions of the Cerebrum.**—That the cerebrum is not essential to life has been demonstrated experimentally many times in birds, fishes, rats, and other animals. Of course, the same kind of proof is not available in man, but there are instances on record in which

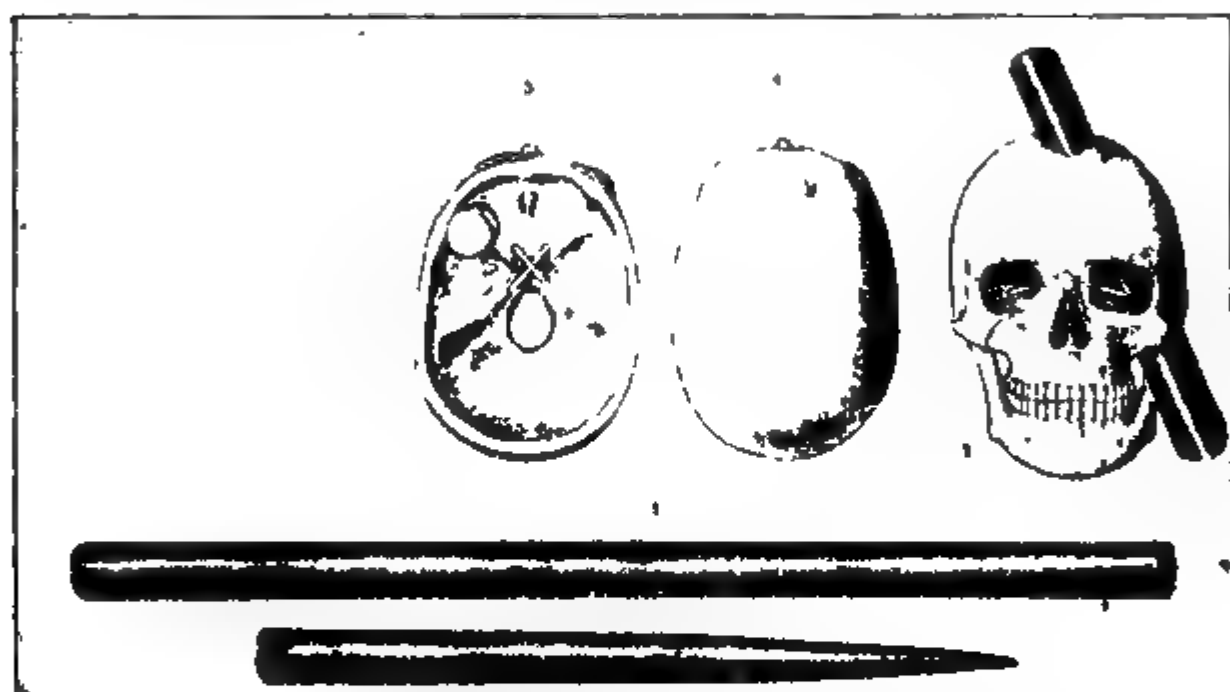


FIG. 298.—Dr. Harlow's case of recovery after the passage of an iron bar through the head.

the destruction of cerebral tissue has been so great as to warrant the statement that in man, as well as in lower animals, life may be maintained without the influence of the cerebrum. A remarkable instance is that of a man who was injured by a premature blast, an iron bar, one inch in diameter, being driven through the skull and brain. Although delirious and unconscious for several weeks, he finally recovered, with but the loss of one eye. He lived more than twenty years after the injury, and performed the work of a coachman and a farm-laborer.

The cerebrum is undoubtedly the seat of the intellectual faculties. A study of the lower animals reveals the fact that according as the hemispheres are developed the signs of intelligence are increased: when these structures are destroyed there is an absence of these manifestations.

When the hemispheres are removed, spontaneous action ceases. In studying the reflex action of the spinal cord in a decapitated frog it was seen that the animal made no attempt to move



or change its position unless some stimulus was applied, and that as soon as this stimulus was withdrawn it lapsed into its original position, remaining therein until again disturbed. If the hemispheres are removed from a pigeon, it will act very much as does the frog. If disturbed, it may fly for a short distance, but at once lapses into a state of apparent unconsciousness, with eyes closed. When the foot is pinched, it will be withdrawn. If a pistol is discharged, the bird will open its eyes and show unmistakably that the report was heard, but the discharge seems to produce no other effect. The fact that there is danger is not appreciated. It seems, therefore, that the faculty is absent by which the bird in health associates danger with such sounds. When the human brain is diseased or injured, something of the same kind is witnessed, and in idiots, whose brains are imperfectly developed, the intellectual faculties are very deficient. Human intelligence is manifested through memory, reason, and judgment.

*Memory* is the basis for the action of the other two faculties; without it there could be neither reason nor judgment. It is the faculty of the mind by which it retains the knowledge of previous thoughts or events, the actual and distinct retention and recognition of past ideas in the mind. Afferent impulses are continually reaching the cells of the cortex of the brain, and these impulses produce impressions more or less permanent. If they were evanescent, passing away almost as soon as received, memory would be impossible; but it is this retention which constitutes memory. If the ideas produced by these impulses come again into existence spontaneously and without effort, this is *remembrance*; if this requires an effort, this is *recollection*, a re-collecting of the impressions originally produced on the cells by afferent impulses.

*Reason* is the faculty of the mind by which is appreciated the nature of nervous impulses, and by which they are referred to their external source—by which an effect is referred to its cause. This reference an idiot cannot make; hence he is said to be “un-reasonable.”

*Judgment* is the faculty of the mind by which a selection is made of the proper means to be used in the attainment of a particular end. Thus if one selects inadequate means for the accomplishment of a given object, it is said that one “lacks judgment.”

The cerebrum is the seat of conscious sensation, as opposed to sensation alone. The gray matter of the spinal cord is said to be sensitive—that is, it responds to stimuli. If the finger is burned, the afferent impulse is received by the gray matter of the cord and a motor impulse passes out to the muscles. But if the impulse travels no farther than the cord, there is no *conscious* sensation. To excite this sensation it must proceed to the gray matter of the cerebral cortex. It is in the cells of the cortex that volitional impulses have their origin. The gray matter, then, is the seat of

the will as well as the conscious center, and when largely diseased or destroyed, the only movements made are involuntary, depending on other nerve-centers.

**Cerebral Localization.**—Although the study of the intellectual faculties is both difficult and abstruse, much advance has in late years been made in the knowledge of the physiology of the cerebrum, so far as relates to the production of voluntary movements and the reception of sensation. Observations upon both man and the lower animals have led to the belief that the power of producing certain movements is limited to certain restricted areas of the brain, and that other areas are connected with sensation.

*Lobulus paracentralls.*

FIG. 299.—Lateral view of the brain: gyri and lobuli marked with antique type, the sulci and fissures with italic type (from Ecker).

These are known respectively as *motor*, *sensorimotor*, or *kinesthetic* or *Rolandic* areas, and *sensory areas*. The localizing of these functions is *cerebral localization*.

These observations had their beginning in 1870. It was found that when galvanic currents were applied to certain parts of the cerebral convolutions movements of particular muscles followed, and that in order to excite these muscles these parts or areas must be stimulated. Although the dog was first experimented upon, other animals (cat, rabbit, and monkey) have furnished like results. In the application of these experiments the animal is put under ether, the skull is trephined, and the poles of a galvanic battery are applied to the convolutions. When on such *stimulation* of a

given spot or area contractions of certain muscles or groups of muscles follow, and when its *extirpation* causes paralysis of these muscles, such spot or area is said to be the motor area for these muscles.

The following statement summarizes in a general way what is known with reference to cerebral localization in the human subject :

*Motor Areas* (Figs. 300, 301).—It has been noted that the

FIG. 300.—The motor areas on the outer surface of the brain.

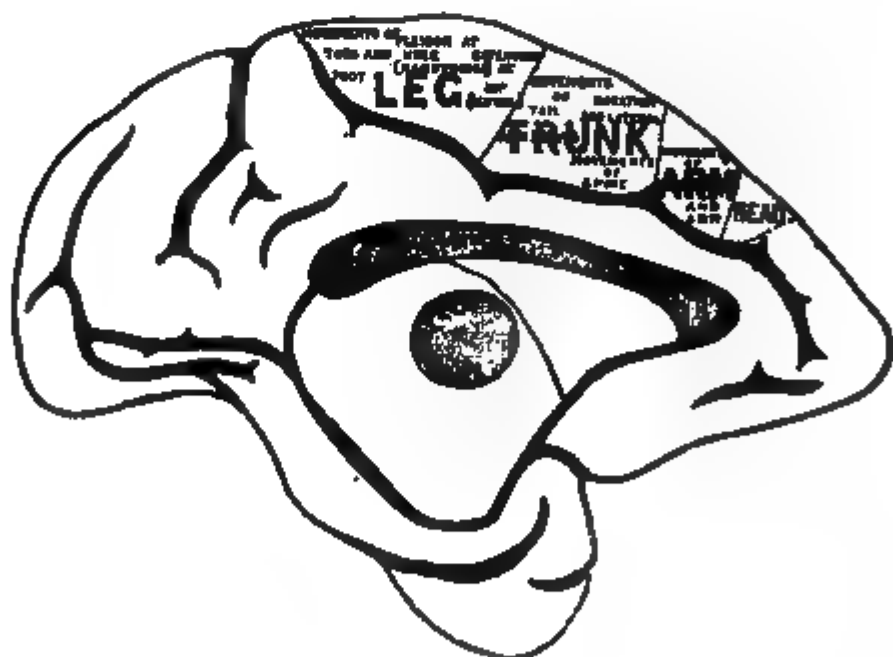


FIG. 301.—The motor areas on the median surface of the brain.

Rolandic area is also called *sensorimotor* and *kinesthetic*. This is because it has been determined that the sensory fibers from the skin and also from muscles terminate in the Rolandic area, as well as that the motor fibers have their origin here.

The motor areas are grouped about the fissure of Rolando and are as follows :

*Head, neck, and face:* Lower two-thirds of the ascending frontal and the bases of the lower and middle transverse frontal convolutions.

*Upper limb:* Upper third of the ascending frontal, base of upper transverse frontal, ascending parietal, and part of the marginal convolutions.

*Lower limb:* Parietal lobule and posterior part of marginal.

*Trunk:* Marginal convolution between the leg and arm.

It is to be understood that the action is in all cases crossed—that is, excitation of one side of the cerebrum causes the movements spoken of to occur on the opposite side of the body, and the same is true of the paralysis which follows disease or injury.

As a result of destruction of the Rolandic area degeneration

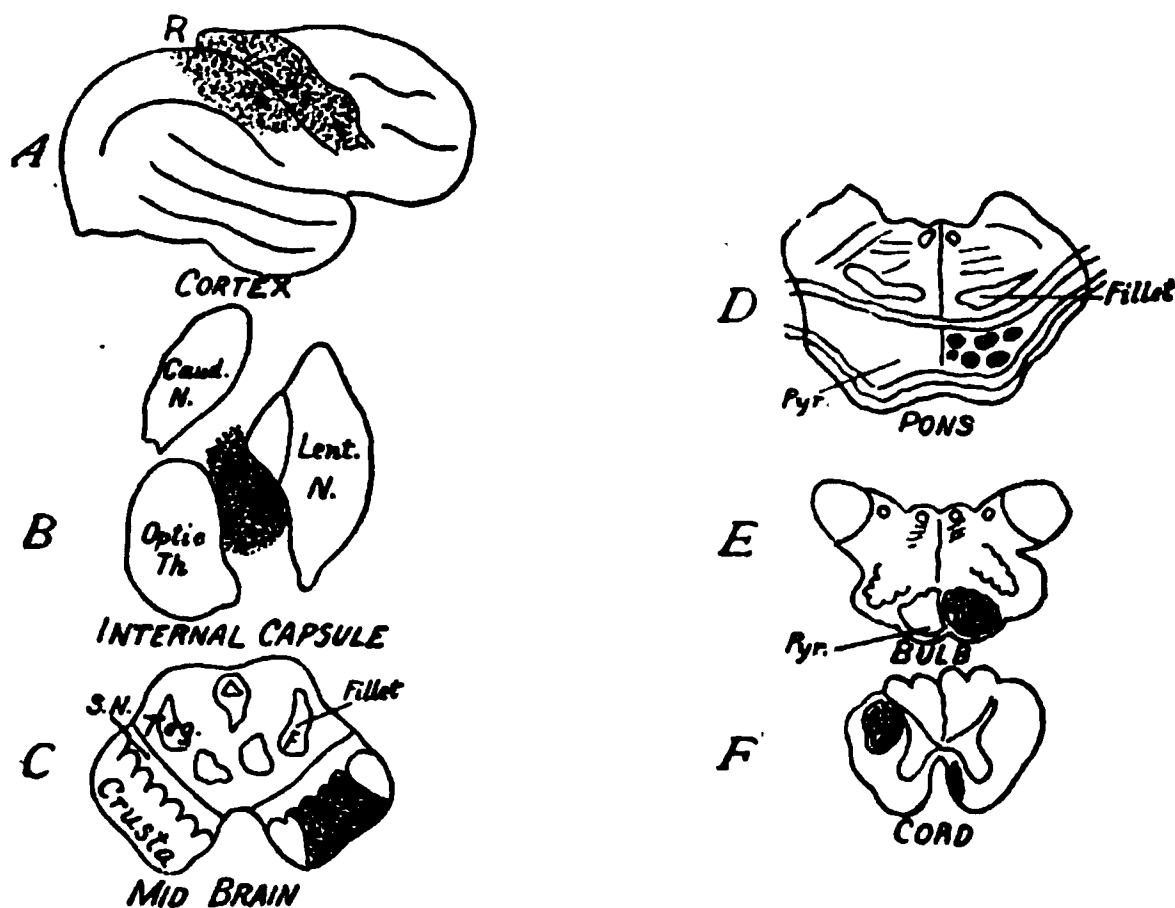


FIG. 302.—Degeneration after destruction of the Rolandic area of the right hemisphere (after Gowers).

occurs, and its course is well shown in the illustration (Fig. 302), in which the shaded portions represent the parts that have undergone degeneration.

*Speech-center.*—Articulate speech requires the exercise of memory and the power of producing certain voluntary movements. Inability to produce articulate speech is known as *aphasia*. If the memory of words is absent while the power to produce the movements remains, it is *amnesic aphasia*, and if the reverse condition exists, it is *ataxic aphasia*. It is believed that the center which presides over language is in the frontal lobe on the left side, and has received from its discoverer the name of *Broca's convolution*. Some localize it in the third frontal convolution; others regard it as being more diffused, and locate the center in the convolutions surrounding the lower end of the fissure

of Sylvius. It is on the left side in persons that are right-handed, and on the right side in those that are left-handed.

*Sensory Areas.*—When a sensory area is *stimulated*, the movement which results is reflex. Thus, if the *auditory area*, which was localized, perhaps incorrectly, by Ferrier in the superior temporosphenoidal convolution, is stimulated, the animal pricks up its ears and turns its head to the opposite side. If a sensory



FIG. 303.—Base of brain: 1, 2, 3, cerebrum; 4 and 5, longitudinal fissure; 6, fissure of Sylvius; 7, anterior perforated spaces; 8, infundibulum; 9, corpora albicantia; 10, posterior perforated space; 11, crura cerebri; 12, pons Varolii; 13, junction of spinal cord and medulla oblongata; 14, anterior pyramid; 14\*, decussation of anterior pyramid; 15, olivary body; 16, restiform body; 17, cerebellum; 19, crura cerebelli; 21, olfactory sulcus; 22, olfactory tract; 23, olfactory bulbs; 24, optic commissure; 25, motor oculi nerve; 26, patheticus nerve; 27, trigeminus nerve; 28, abducens nerve; 29, facial nerve; 30, auditory nerve; 31, glossopharyngeal nerve; 32, pneumogastric nerve; 33, spinal accessory nerve; 34, hypoglossal nerve.

area is *extirpated*, there is a loss of the sense presided over by this area.

*Visual Area.*—This is located in the occipital lobe and the angular gyrus.

*Auditory Area.*—Ferrier located this in the superior temporosphenoidal convolution.

The location of other areas is a matter of considerable doubt.

**Cranial Nerves** (Fig. 303).—The cranial nerves have their origin in the gray matter at the base of the brain, and they escape from the skull by various openings, or *foramina*, to reach the parts to which they are distributed. The only exception to this is the spinal accessory, a part of which arises from the gray matter of the cord. Among the cranial nerves are those of special sense, of motion, and nerves having both motor and sensory properties. The points at which they leave the brain are spoken of as their *apparent origin*, but this is only apparent, for they can be traced into the brain-substance, to collections of nerve-cells, nerve-centers, to which the name *nuclei* has been given. The nucleus of a nerve is its real origin.

Of cranial nerves there are 12 pairs, the *number* of each indicating the order, from before backward, in which it escapes from the cavity of the cranium: 1. Olfactory; 2. Optic; 3. Motor oculi communis; 4. Patheticus or trochlearis; 5. Trigemini; 6. Abducens; 7. Facial; 8. Auditory; 9. Glossopharyngeal; 10. Pneumogastric; 11. Spinal accessory; 12. Hypoglossal.

The first two nerves, the olfactory and the optic, will be considered in connection with the senses of smell and sight.

**Motor Oculi.**—The third nerve, motor oculi, motor oculi communis, or oculomotorius, leaves the surface of the brain at the inner surface of the crus cerebri, just in front of the pons Varolii. Its real origin is, however, a nucleus in the floor of the aqueduct of Sylvius. It escapes from the cranium through the sphenoidal fissure, and is distributed to the superior, internal, and inferior recti and to the inferior oblique. It also supplies the levator palpebræ superioris, and sends a branch to the ophthalmic, lenticular, or ciliary ganglion. Another way to describe its distribution is to say that it supplies the levator palpebræ and all the muscles that move the eyeball, except the superior oblique and external rectus.

The action of these muscles is largely indicated by their names. The levator palpebræ by its contraction raises the upper eyelid. The internal rectus turns the eyeball inward toward the nose, and the external rectus turns it outward. The direction of action and the point of attachment of the superior rectus are such that when it contracts the eyeball is not only turned upward, but it is also rotated slightly inward; this is corrected by the action of the inferior oblique, so that the two acting together produce a movement directly upward. The same deviation inward follows when the eye is turned downward by the inferior rectus, and a similar correction is made by the action of the superior oblique. If the external and superior recti act together, the movement of the eyeball is in the direction of the diagonal—that is, outward and upward; the conjoint action of the external and inferior recti causes the eyeball to move outward and downward, and a corresponding action results when the other adjacent recti are brought

into play. If the recti act alternately, the eyeball will be rotated completely, as in looking around a room from one side to the other and back again, from the floor to the ceiling. The motor oculi is purely a motor nerve. When stimulated, contraction is produced in the muscles to which it is distributed; when the nerve is divided, these muscles are paralyzed.

*Paralysis of the Motor Oculi.*—When the motor oculi is paralyzed, the following are the results:

(a) *External strabismus*, which consists in a turning of the eye outward. The retention of the eye in its normal position requires the conjoint action of the internal and external recti. In paralysis of the motor oculi the internal rectus has lost its innervation, and therefore its power to contract, and the external rectus, which receives its nervous supply from another nerve (the abducens), having lost its antagonist, turns the eye outward.

(b) *Lusitas*.—After external strabismus has been produced the eye remains in that condition, for the muscles which could move it in any other direction have been paralyzed. This immobility is called “lusitas.”

(c) *Ptosis*.—The levator palpebræ superioris is also paralyzed, and the upper eyelid droops, constituting *ptosis*. The ability to close the eye still remains, as this is the act of the orbicularis palpebrarum, which is not innervated by the third, but by the seventh, nerve.

(d) *Mydriasis*.—A branch of the motor oculi goes to the ciliary ganglion, which gives off the ciliary nerves that supply the iris. Accompanying the manifestations of paralysis of the motor oculi already mentioned there is in addition a dilatation of the pupil, or *mydriasis*. The diminution of the size of the pupil following the action of light upon the retina does not take place when this nerve is paralyzed. The contraction of the pupil is a reflex act requiring the integrity of the optic nerve, which serves as a carrier of the luminous impressions to the brain, and of the motor oculi, which is the efferent nerve in this act.

(e) *Inability to Focus*.—The muscle concerned in focusing the eye for short distances is the ciliary. The power to focus is lost in paralysis of the motor oculi. Paralysis of the motor oculi may be due to disease of the brain or to pressure on the nerve. If the trunk of the nerve is affected, all the physical signs mentioned may be observed, while if a single branch only is involved, the effect will be limited to the part to which that branch is distributed.

*Trochlearis*.—The apparent origin of the trochlearis or patheticus is on the outer side of the crus cerebri, in front of the pons, and its real origin is a nucleus continuous with that of the motor oculi. The trochlearis leaves the cranium by the sphenoidal fissure, and is distributed to but one muscle, the superior oblique.

When this nerve is paralyzed the patient cannot turn the eye outward and downward; the action of the superior oblique is, therefore, to turn the eye outward and downward. If the head is not turned toward either side when this nerve is paralyzed, the only thing observable is that the patient sees double when he looks downward, and the image perceived by the affected eye is oblique and below that seen by the eye that is affected. For a further discussion of the ocular muscles see p. 556.

**Trigeminus.**—This nerve, which is also called “trifacial,” has received its names from the fact that it has three subdivisions, and its latter name from the fact that it is distributed in the main to

FIG. 304.—General plan of the branches of the fifth pair: 1, lesser root of the fifth pair; 2, greater root, passing forward into the Gasserian ganglion; 3, placed on the bone above the ophthalmic division, which is seen dividing into the supra-orbital, lacrimal, and nasal branches, the latter connected with the ophthalmic ganglion; 4, placed on the bone close to the foramen rotundum, marks the superior maxillary division; 5, placed on the bone over the foramen ovale, marks the inferior maxillary division (after a sketch by Charles Bell).

the parts about the face. It arises by two roots, anterior and posterior. The anterior root, the smaller, is purely motor; the posterior root, the larger, is sensory, and is characterized anatomically by having upon it the Gasserian ganglion. The nerve leaves the brain at the side of the pons Varolii. The real origin of the motor root is a nucleus in the floor of the fourth ventricle; the sensory root arises from a nucleus on a level with the middle of the superior peduncle of the cerebellum, just internal to the margin of the fourth ventricle. Some authorities give it a more extensive origin, from the pons through the medulla and as far as the posterior cornua of the gray matter of the spinal cord.



The motor root passes beneath the Gasserian ganglion, and takes no part in its formation.

Beyond the ganglion the fifth nerve divides into three parts: (1) ophthalmic; (2) superior maxillary; and (3) inferior maxillary.

(1) *Ophthalmic Division*.—This division, which leaves the cranium by the sphenoidal fissure, is distributed to the tentorium cerebelli, the eyeball, the Schneiderian membrane, the lacrimal gland, and the skin about the forehead and nose; and also supplies branches to the ciliary ganglion. It contains fibers from the posterior root only; none from the anterior.

(2) *Superior Maxillary Division*.—This division of the fifth pair leaves the cranial cavity by the foramen rotundum. It is distributed to the dura mater, the sphenopalatine ganglion (Meckel's), the skin of the temple and cheek, the teeth, the gums, the mucous membrane of the upper jaw and upper lip, the mucous membrane of the lower part of the nasal passages, and the skin of the lower eyelid, side of nose, and upper lip. There are no fibers of the anterior root in this division.

(3) *Inferior Maxillary Division*.—As has already been stated, there is no anatomic connection between the motor root of the fifth nerve and the Gasserian ganglion. From this ganglion are given off nerve-fibers which join the motor root, together making the inferior maxillary division, which escapes through the foramen ovale. It is distributed to the dura mater, the otic ganglion, the mucous membrane of the cheek and skin, the mucous membrane of the lower lip, the anterior wall of the external auditory meatus, the front of the external ear and the skin of the adjacent temporal region, the submaxillary gland and ganglion, the mucous membrane of the mouth and tongue; to the papillæ at the tip, the edges, and anterior two-thirds of the tongue, and to the teeth and gums of the lower jaw. It also supplies the following muscles: Temporal, masseter, pterygoid, mylohyoid, and anterior belly of the digastric.

*Physiologic Properties of the Trigemini*.—The trigeminus is the largest of the cranial nerves, and its functions are many and important. It supplies the parts to which it is distributed with the general sensibility they possess. If it is divided, there is complete absence of sensation (anesthesia) of the face on the corresponding side. So pronounced is this anesthesia that no amount of irritation applied to such ordinarily sensitive parts as the cornea will produce any effect. An animal thus experimented upon seems entirely unconscious of the irritation. Experimenters have gone so far as to exsect the eyeball and apply hot irons to the skin without causing pain to the animal experimented upon.

Neuralgia of the face, headache, and toothache are all due to some interference with the normal functions of this nerve. It is

not an uncommon thing to hear patients complain of headaches which seem to them to be in the brain itself. These deep-seated headaches may be due to affections of one or more of the recurrent branches which come off from the divisions of the nerve, and which are distributed to the dura mater and bones of the skull.

*Lingual (Gustatory) Nerve.*—This nerve is sometimes called the “lingual branch of the fifth nerve.” It is the branch which is distributed to the mucous membrane of the mouth and the gums, and to the mucous membrane and papillæ of the tongue. It supplies the tongue with tactile sensibility, a quality of great advantage in enabling one to detect the physical properties of food, to

FIGS. 305, 306.—Distribution of the cutaneous sensitive nerves upon the head: *oma*, *orni*, the occiput. maj. and minor (from the N. cervical II. and III.); *am*, N. auricular magn. (from N. cervic. III.); *ca*, N. cervical superfic. (from N. cervic. III.); *V<sub>1</sub>*, first branch of the fifth (*so*, N. supraorbit.; *st*, N. supratrochl.; *it*, N. infratrochl.; *e*, N. ethmoid.; *l*, N. lacrimal.); *V<sub>2</sub>*, second branch of the fifth (*sm*, N. subcutan. malse seu zygomaticus); *V<sub>3</sub>*, third branch of fifth (*at*, N. auriculotempor.; *b*, N. buccinator; *m*, N. mental.); *B*, posterior branches of the cervical nerve.

recognize in it the presence of hard objects which it would be injurious to swallow, and to determine when it is ready for deglutition. Besides this tactile sensibility the lingual nerve, according to some authorities, supplies the anterior two-thirds of the tongue with the sense of taste, a special sense, and this power is lost when the fifth pair or the lingual branch is divided. For a further consideration of this nerve see p. 535.

*Mastication.*—The muscles that have been mentioned as receiving branches of the inferior maxillary division are those concerned in the act of mastication. In this act the temporal and masseter close the mouth, the mylohyoid and digastric open it, while the pterygoids produce the lateral movement of the lower jaw. Division of the inferior maxillary division paralyzes, therefore, all

these muscles. If it is divided on one side, the muscles on the other side can still perform the act, but in an imperfect manner; if divided on both sides, all masticatory movements will be abolished.

*Anastomosis of the Fifth Pair.*—Besides the branches already mentioned, there are others which are termed *anastomotic branches*. Although the upper, middle, and lower parts of the face are supplied with sensation by the ophthalmic, superior maxillary, and inferior maxillary divisions respectively, still the boundaries of each are not absolute. Thus the skin of the nose is supplied by fibers from the ophthalmic and superior maxillary, and the skin of the temporal region is supplied from both the superior and inferior maxillary divisions. In addition to these branches, there are some which unite with other nerves and give a certain amount of sensibility to the parts to which these nerves are distributed. A striking instance of this is the branch which anastomoses with the facial nerve. This nerve is at its origin purely motor, and is distributed to the muscles of the face. These muscles are endowed with sensibility; but this is not due to fibers of the facial nerve, but to those of the fifth nerve, which anastomose with the facial and go with it to its termination in the muscles.

*Connection of the Fifth Pair with the Special Senses.*—After division of the fifth nerve the special senses of smell, sight, taste, and hearing are seriously affected. The Schneiderian membrane becomes swollen, and later assumes a fungous condition and bleeds readily when touched. There is besides an accumulation of altered mucus in the nasal passages. The eye also undergoes marked changes: The conjunctiva becomes congested and the cornea opaque; later, most of the structures of the eye suffer from inflammatory changes to the degree of destruction. The sense of taste may likewise be lost, not only in the anterior two-thirds of the tongue, but also in the posterior third as well. Besides, the sense of hearing may also be greatly impaired.

The explanation of these changes is not an easy one. Some authorities regard them as due to disturbance of trophic influences. The nerve-fibers which form the posterior or sensory root of the fifth pair in passing through the Gasserian ganglion are reinforced by fibers which have their origin in this collection of nerve-cells. Each of the three divisions of the trigeminus contains, therefore, fibers of the posterior root, and in addition fibers from the ganglion. The latter fibers are distributed to the structures to which the accessory fibers are distributed, and they are regarded as trophic nerves—that is, as nerves which regulate the nutrition of the parts to which they go. Among these parts are the mucous membrane of the nose, the cornea, the conjunctiva, and the tongue, and the loss of the special senses is believed to be due to altered nutrition of the affected parts. The sense of sight

is resident in the retina and optic nerve, but it may be as perfectly abolished by rendering opaque the tissues through which light reaches these structures as by dividing the optic nerve. Thus in cases where a tumor presses upon the trigeminus in front of the ganglion, not only may there be an alteration of the nutrition of the skin of the face, as evidenced by an herpetic eruption, but there may be also the corneal ulceration already referred to. In like manner the olfactory nerves are the nerves of smell, but if the nasal mucous membrane is so affected in its nutrition as to render the function of the nerves impossible, the sense of smell is as certainly abolished as if the olfactory bulb was broken up. This interference with the normal action of the nerves is seen in catarrhal affections of the nose, in which the sense of smell is much obtunded and sometimes even lost.

Some authorities, however, question the existence of specific trophic nerves. Stewart says that up to the present "*no unequivocal proof, experimental or clinical, has ever been given of the existence of specific trophic nerves.*" These authorities consider that the inflammatory changes occurring in the eye, for instance, are due to the presence of foreign bodies lodging on the eyeball, which has lost its sensibility; that if the eye is so protected that irritating substances cannot injure it, the degenerative changes take place only after a considerable time; and that when they do occur it is probably even then due to injury, for it is a most difficult thing to protect the eye for a long time from all sources of irritation. Thus in a case reported by Shaw, in which both the fifth and the third nerves were paralyzed, due to the pressure of a tumor at the base of the brain, no change took place in the nutrition of the eye. The orbicularis could still close the eye, and the protection which this gave was augmented by the ptosis. After many months the growth of the tumor involved the facial nerve, and as the eye could then not be closed, inflammatory changes soon set in and sight was destroyed.

Gowers also reports a case in which the patient lived for seven years with complete paralysis of the fifth nerve, yet the eye remained free from disease and the sight was unimpaired.

Kirkes, on the other hand, is an advocate of the existence of the "trophic influence of nerves," although he states that the proof that there are distinct trophic nerve-fibers anatomically is not very conclusive. He thinks that the division or disease of the fifth nerve, for instance, acts as a *predisposing* cause, and the dust which falls on the cornea as the *exciting* cause. He gives one instance of disturbance of nutrition which it is difficult to account for except on the theory of trophic nerves. He says: "Many bed-sores are due to prolonged confinement in bed with bad nursing; these are of slow onset. But there is one class of bed-sores which are acute: these are especially met with in cases of

paralysis due to disease of the spinal cord ; they come on in three or four days after the onset of the paralysis in spite of the most careful attention ; they cannot be explained by vasomotor disturbance nor by loss of sensation ; there is, in fact, no doubt they are of trophic origin ; the nutrition of the skin is so greatly impaired that the mere contact of it with the bed for a few days is sufficient to act as the exciting cause of the sore."

The subject is one of great importance, but must be regarded as still unsettled.

*Ganglia of the Trigeminus.*—Besides the Gasserian ganglion, there are, in connection with the fifth nerve, four ganglia which are by some writers described as a part of the sympathetic system. They are the ciliary or ophthalmic, the sphenopalatine or Meckel's, the otic or Arnold's, and the submaxillary.

The *ciliary ganglion* belongs, according to some authorities, to the third rather than to the fifth nerve. It is not larger than the head of an ordinary pin, and is situated in the orbit. The branches by which other nerves communicate with it are called its "roots" ; of these there are three : The *sensory*, from the ophthalmic division of the fifth ; the *motor*, from the motor oculi ; and the *sympathetic*, from the cavernous plexus of the sympathetic. The nerves that go off from it are the short ciliary nerves, which, joining with the long ciliary nerves, form the nasal branch of the ophthalmic division, and together they are distributed to the ciliary muscle, the iris, and the cornea. These nerves supply motion to the sphincter and dilator pupillæ, sensibility to the iris, choroid, and sclerotic, and vasomotor influences to the blood-vessels of the iris, choroid, and retina. If the trophic influence already spoken of exists, it must be conveyed to the eye through the ciliary nerves.

The *sphenopalatine* or *Meckel's ganglion*, which is the largest of the four, is situated in the sphenomaxillary fossa. This ganglion also has three roots : The *sensory*, sphenopalatine, from the superior maxillary division of the fifth ; the *motor*, large superficial petrosal nerve from the facial ; and the *sympathetic*, large deep petrosal nerve from the carotid plexus of the sympathetic. The Vidian nerve is made by the union of these two latter nerves. The nerves from this ganglion are distributed to the posterior portion of the nasal passages and the hard and soft palate, giving them sensibility ; to the levator palati and azygos uvulæ, giving them the power of motion ; and to the blood-vessels of this region.

The *otic* or *Arnold's ganglion* is situated on the inner side of the inferior maxillary division of the fifth, just below the foramen ovale. It likewise has three roots : The *sensory*, from the inferior maxillary and glossopharyngeal ; the *motor*, from the facial and inferior maxillary ; and the *sympathetic*, from the plexus around

the meningeal artery. Its branches of distribution are to the tensor tympani, the tensor palati, and a small one to the chorda tympani. The mucous membrane of the tympanum and the Eustachian tube is also supplied by this ganglion.

The *submaxillary ganglion*, which is situated near the submaxillary gland, receives branches of communication from the lingual branch of the fifth, chorda tympani, and sympathetic plexus around the facial artery. Its branches of distribution are to the mucous membrane of the mouth and Wharton's duct, also to the submaxillary gland.

**Abducens.**—This nerve, which has its real origin in the floor of the fourth ventricle, emerges from the cranium by the sphenoidal fissure, and is distributed to the external rectus muscle. It is a motor nerve, as is shown by the contraction of this muscle when the nerve is stimulated, and by its paralysis when the nerve is divided.

*Paralysis of Abducens.*—When from any cause this nerve is so injured as to deprive it of its function, the internal rectus, having lost its antagonist, the external rectus, turns the eye inward toward the nose, producing internal strabismus. There may also be some contraction of the pupil, because the radiating fibers of the iris, which cause dilatation of the pupil, are to a certain extent deprived of their innervation, this being supplied from the sympathetic, some of the nerves of which system run along with the abducens, and when this nerve is injured, these sympathetic fibers may also be involved. It is said that the abducens is more frequently implicated in fractures at the base of the skull than any other cranial nerve.

**Facial Nerve.**—The facial nerve leaves the medulla oblongata at the groove between the olivary and the restiform bodies. Its real origin is a nucleus in the floor of the fourth ventricle. It leaves the cranium by the internal auditory meatus, through which and the aqueduct of Fallopius it passes to emerge at the stylomastoid foramen. In the older nomenclature, in which there were but nine pairs of nerves, the facial was associated under the name of seventh nerve with the auditory nerve, in company with which it enters the auditory meatus; the facial, from its firm consistency, being called the *portio dura*, and the auditory, on account of its opposite quality, being called the *portio mollis*.

The facial has a very extensive distribution—the muscles of the face and external ear, the stylohyoid, posterior belly of the digastric, the platysma myoides, and the stapedius. It also gives off the chorda tympani, which is distributed to the submaxillary gland and ganglion, to the inferior lingualis muscle, and to the sublingual gland. Besides these it has most important branches of communication with the sympathetic system and with the glossopharyngeal, pneumogastric, and trigeminus nerves.



*Physiologic Properties of the Facial.*—The facial is, originally, a purely motor nerve, and whatever sensibility is possessed by the parts to which it is distributed is not due to facial fibers, but to anastomotic fibers from other nerves, principally the fifth. The most pronounced function of the facial is its relation to expression. The so-called “expression” of the face is caused by different degrees of contraction of the facial muscles, and the different expressions, such as of fear, of anger, etc., are due to contraction of different muscles. The facial is therefore said to be the “nerve of expression,” and when it is divided and the muscles paralyzed, the reason for this title is readily understood.

*Facial Paralysis.*—When the facial nerve is divided or its functions otherwise abolished, the following are the results:

(1) *Effect of Facial Paralysis on Facial Expression.*—A complete loss of expression follows on the affected side; the wrinkles on that side are obliterated and the face is flattened.

(2) *Effect of Facial Paralysis on the Eye.*—The muscle which closes the eye is the orbicularis palpebrarum; this muscle is innervated by the facial nerve, and in paralysis, therefore, the eye remains permanently open, the power to close it being lost. Inasmuch as the act of winking is but a rapid partial closing of the eye, this act is also abolished and the eyeball is liable to become dry. The act of winking spreads the tears which keep the eye moist. Unless provided against, this exposure of the eye may result in injury (p. 519).

(3) *Effect of Facial Paralysis on the Mouth.*—The mouth is drawn by the unparalyzed muscles to the unaffected side. It is impossible to approximate the lips of the affected side to a tumbler or cup; consequently in drinking therefrom, unless the head is thrown back, fluids will dribble from the corners of the mouth. The buccinator muscle being paralyzed, food finds its way into the space between the cheek and the gum, and mastication is seriously impeded. The lips being paralyzed, the consonants *b* and *p* cannot be pronounced distinctly. If the tongue is protruded, it seems to be deviated toward the affected side; but this is only apparent, for if the mouth is placed in the normal position it will be seen that the tongue is unaffected.

(4) *Effect of Facial Paralysis on Taste.*—Accompanying facial paralysis may be impairment or abolition of the sense of taste. Authorities are not agreed as to the explanation of this result, but it is doubtless due to interference with the chorda tympani. Some attribute it to the influence which this nerve exercises over the circulation in the tongue and on the secretion of saliva: others regard the chorda tympani as the nerve of taste to the anterior two-thirds of the tongue, and as taking part in forming the gustatory nerve or lingual branch of the trigeminus. Indeed, there is a difference of opinion among anatomists as to the true source of the chorda tympani, at least so far as concerns those fibers which

are connected with the sense of taste ; some look upon it as a part of the fifth, some as a part of the seventh, and still others as a part of the ninth or glossopharyngeal.

**Auditory.**—The auditory nerve has its apparent origin from the lower border of the pons, in the groove between the olivary and restiform bodies. Its real origin is in the floor of the fourth ventricle. As already stated, the auditory nerve enters the internal auditory meatus with the facial nerve. It is distributed to the internal ear, and is the special nerve of the sense of hearing. It will further be discussed in connection with that special sense.

**Glossopharyngeal.**—The superficial origin of the glossopharyngeal nerve is from the upper part of the medulla, in the groove between the olivary and restiform bodies. Its real origin is a nucleus in the lower part of the floor of the fourth ventricle. It escapes from the cranium through the jugular foramen, together with the pneumogastric and spinal accessory nerves. Its branches of communication are with the pneumogastric, facial, and sympathetic nerves. The glossopharyngeal gives off the tympanic branch, the nerve of Jacobson, which is distributed to the fenestra rotunda, the fenestra ovalis, and the lining membrane of the tympanum and Eustachian tube. As its name implies, the glossopharyngeal is distributed to the tongue and pharynx. The glossal portion supplies the mucous membrane of the posterior third of the tongue, the tonsils, and the pillars of the fauces and soft palate, while the pharyngeal portion is distributed to the pharyngeal mucous membrane and to the muscles concerned in a part of the act of deglutition—namely, the styloglossus, digastric, and stylopharyngeus, and the superior and middle constrictors.

**Physiologic Properties.**—The sensibility of the parts to which the glossopharyngeal nerve is distributed is due to this nerve. It is also a nerve of special sense, supplying the posterior third of the tongue and the palate with the sense of taste ; and, finally, it is the motor nerve for the muscles enumerated which are concerned in passing the food from the back of the mouth into and through the pharynx to the esophagus in the act of deglutition.

**Vagus.**—This nerve is also called *pneumogastric*, from two of the important organs, the lungs and stomach, to which it is distributed. Its apparent origin is by eight or ten filaments from the groove below the glossopharyngeal, while its deep origin is from a nucleus in the floor of the fourth ventricle, below and continuous with that of the same nerve.

At the jugular foramen, by which it escapes from the cranium, is found the ganglion of the pneumogastric or the jugular ganglion. The pneumogastric receives branches from the spinal accessory, facial, hypoglossal, and anterior branches of the first and second cervical nerves. It assists in forming the pharyngeal, laryngeal, pulmonary, and esophageal plexuses. Among its important branches are the superior and inferior laryngeal nerves, the cardiac



FIG. 307.—View of the glossopharyngeal, pneumogastric, spinal accessory, and hypoglossal nerves of the left side: 1, pneumogastric nerve in the neck; 2, ganglion of its trunk; 3, its union with the spinal accessory; 4, its union with the hypoglossal; 5, pharyngeal branch; 6, superior laryngeal nerve; 7, external laryngeal; 8, laryngeal plexus; 9, inferior or recurrent laryngeal; 10, superior cardiac branch; 11, middle cardiac; 12, plexiform part of the nerve in the thorax; 13, posterior pulmonary plexus; 14, lingual or gustatory nerve of the inferior maxillary; 15, hypoglossal, passing into the muscles of the tongue, giving its thyrohyoid branch, and uniting with twigs of the lingual; 16, glossopharyngeal nerve; 17, spinal accessory nerve, uniting by its inner branch with the pneumogastric, and by its outer passing into the sternomastoid muscle; 18, second cervical nerve; 19, third; 20, fourth; 21, origin of the phrenic nerve; 22, 23, fifth, sixth, seventh, and eighth cervical nerves, forming with the first dorsal the brachial plexus; 24, superior cervical ganglion of the sympathetic; 25, middle cervical ganglion; 26, inferior cervical ganglion united with the first dorsal ganglion; 27, 28, 29, 30, second, third, fourth, and fifth dorsal ganglia (from Sappey, after Hirschfeld and Leveillé).

and the gastric branches. The pharyngeal branch is distributed to the mucous membrane and muscles of the pharynx and to the

muscles of the soft palate. Its esophageal branches supply the mucous membrane and muscular coat of the esophagus, so that the act of deglutition, which begins in the mouth and is continued in the pharynx, is completed by the esophagus. The superior laryngeal nerve is distributed to the cricothyroid muscle and to the inferior constrictor, and communicates with the superior cardiac nerve. Its further distribution is to the mucous membrane of the epiglottis and larynx as far as the vocal cords.

The superior laryngeal nerve is the sensitive nerve of the larynx. This sensibility is of great importance as a protection of the larynx and the respiratory organs below it from the entrance of foreign bodies, which would set up dangerous inflammatory processes. The instant such a substance touches the surfaces supplied by this nerve a violent expulsive cough occurs which ejects it. If the nerve is paralyzed, as it may be after diphtheria or in connection with brain disease, this protection is absent, and, owing to paralysis of the cricothyroid, the ability to make tense the vocal cords is lost and the voice is hoarse.

The inferior or recurrent laryngeal nerve is distributed to all the muscles of the larynx except the cricothyroid. It sends branches to the mucous membrane and muscular coat of the esophagus, to similar structures of the trachea, and to the inferior constrictor. It is the motor nerve of the larynx, and may be paralyzed under the same conditions as were mentioned in connection with the superior laryngeal, and all motion of the vocal cords is abolished. One nerve may alone be paralyzed, as when pressed upon by a tumor, when the corresponding vocal cord would alone be motionless.

The cardiac branches of the pneumogastric terminate in the superficial and deep cardiac plexuses. The pulmonary branches assist in forming the pulmonary plexuses, the branches of which are distributed to the lungs. The esophageal branches form the esophageal plexus or plexus gulæ. The gastric branches, which are the terminal filaments of the nerve, are distributed to the stomach and to the celiac, splenic, and hepatic plexuses, the latter two supplying the liver and spleen.

In mentioning some of the branches of the pneumogastric, their functions have also been referred to. In addition to these functions the movements of the stomach and the intestines are also performed under the influence of this nerve. It is through the cardiac branches that the inhibitory impulses from the medulla are sent to the heart. Through the pulmonary branches impulses reach the respiratory center and influence respiration. Reference has previously been made to the depressor fibers, which run in the pneumogastric to the vasomotor center, inhibiting its action and thus diminishing the work of the heart.

**Spinal Accessory Nerve.**—This nerve has two parts—one arising

from a nucleus in the medulla below that of the pneumogastric, and the other from the intermediolateral tract of the cord. The former is the *accessory*, and the latter the *spinal*, portion. The accessory portion joins the pneumogastric, and is distributed through the pharyngeal and superior laryngeal branches of that nerve. It is also probable that the fibers of the pharyngeal branch going to the muscles of the soft palate are fibers of this portion of the spinal accessory.

The inferior laryngeal nerve also contains fibers from this nerve, probably from the internal, anastomotic, or accessory portion, and experiments demonstrate that the power which the larynx possesses to produce vocal sounds is due to these fibers, for when the spinal accessory is torn out this power is lost. The other movements of the larynx, those which take place during respiration, are not interfered with under these circumstances, but only those of phonation. The inferior laryngeal nerve is, then, only partially made up of spinal accessory fibers: these fibers preside over phonation. The other fibers, which are probably derived from the facial, hypoglossal, or cervical, or all of them, provide the nervous influence for the other movements. If the entire nerve is divided, the laryngeal movements of both phonation and respiration will cease.

The spinal or external portion is distributed to the trapezius and sternomastoid muscles; it is therefore sometimes called the "muscular branch." This branch is believed to be brought into requisition when these muscles are needed for more than their ordinary activity, for the nervous force to supply the latter is furnished by cervical nerves. In unusual straining or in lifting, or in the production of prolonged cries, these muscles are brought into action, and to supply the additional innervation which these acts seem to require is believed to be the office of the muscular branch of the eleventh nerve. The spinal accessory is, then, a motor nerve, although some writers regard a portion of the fibers of the accessory part as being sensory.

**Hypoglossal.**—The apparent origin of this nerve is by filaments, from 10 to 15 in number, from the groove between the pyramidal and olivary bodies: its real origin is in a nucleus in the floor of the fourth ventricle. It sends branches of communication to the pneumogastric, the sympathetic, the first and second cervical, and the gustatory. It is distributed to the sternohyoid, sternothyroid, omohyoid, thyrohyoid, styloglossus, hyoglossus, geniohyoid, and geniohyoglossus muscles. It is a motor nerve to the tongue, so much so that it has been called the "motor linguæ." The movements over which it presides are those concerned in mastication and deglutition and in the production of articulate speech. When this nerve is paralyzed on one side, the tongue, when protruded, is directed toward the paralyzed side. When both nerves are involved in the paralysis all motion of the tongue ceases.

THE SENSES.

It is by the senses that the individual is brought into relation with the world outside him. The senses are five in number : (1) General sensibility ; (2) Smell ; (3) Taste ; (4) Sight ; and (5) Hearing.

**General Sensibility.**—This kind of sensibility is so called because it is generally distributed over the entire body in the skin, and in those parts of mucous membrane adjacent to the skin. It is composed of a variety of sensations which are excited by a variety of stimuli, but it is still an unsettled question whether the nerves which conduct the impulses that excite these sensations are in all instances the ordinary sensory nerves of the skin, or whether they are special nerves, each one conducting only its own special stimulus. In treating of the subdivisions of general sensibility this question will again be referred to.

**Sense of Touch.**—The sense of touch, or *tactile sensibility*, depends upon the existence of nerves and nerve-endings (p. 64) in the skin and other portions of the body in which the function exists. It gives knowledge of such qualities as hardness or softness, roughness or smoothness, sharpness or dulness, etc. ; by it we become acquainted with the shape and consistency of objects, and are made aware of the presence or absence of irritating qualities in certain substances. The pungent vapors of some gases excite in the nose the ultimate fibers of distribution of the fifth pair of nerves, and not those of the first pair, and it is incorrect to describe this sensation as a smell. It is as truly a tactile sensation as when a sharp-pointed instrument is brought in contact with the skin. The same is true of pungent liquids applied to the tongue, which are commonly, but erroneously, said to be tasted.

The difference in the tactile sensibility of different portions of the body is shown in the following table :

TABLE OF VARIATIONS IN THE TACTILE SENSIBILITY OF DIFFERENT PARTS.

The measurement indicates the least distance at which the two points of a pair of compasses can be separately distinguished (E. H. Weber).

Tip of tongue . . . . .	1 mm.
Palmar surface of third phalanx of forefinger . . . . .	2 "
Palmar surface of second phalanges of fingers . . . . .	4 "
Red surface of under lip . . . . .	4 "
Tip of the nose . . . . .	6 "
Middle of dorsum of tongue . . . . .	8 "
Palm of hand . . . . .	10 "
Center of hard palate . . . . .	12 "
Dorsal surface of first phalanges of fingers . . . . .	14 "
Back of hand . . . . .	25 "
Dorsum of foot near toes . . . . .	37 "
Gluteal region . . . . .	37 "
Sacral region . . . . .	37 "

TABLE OF VARIATIONS, ETC.—*Continued.*

Upper and lower parts of forearm . . . . .	37 mm.
Back of neck near occiput . . . . .	50 "
Upper dorsal and mid-lumbar regions . . . . .	50 "
Middle part of forearm . . . . .	62 "
Middle of thigh . . . . .	62 "
Mid-cervical region . . . . .	62 "
Mid-dorsal region . . . . .	62 "

Weber, who has investigated thoroughly the subject of tactile sensibility, says that in order to distinguish the two points of the compasses as such, there must be unexcited nerve-endings between the points of the skin that are touched by them, and the greater the number of these, the more distinctly are they recognized as being separate. Tactile sensibility is a function which can be educated to a high degree.

*Case of Laura D. Bridgman.*—No better illustration could be given of the degree of perfection to which this sense can be brought than that of the deaf, dumb, and blind girl, Laura Dewey Bridgman. When about two years old this child had scarlet fever, as a result of which she lost the senses of sight, hearing, taste, and smell. Although, about eleven years after, the sense of smell returned to a slight degree, the other senses mentioned were permanently absent. In describing her case, Prof. Mussey, Prof. of Anatomy and Surgery at Dartmouth College, Hanover, N. H., where Laura lived, states that she possessed not merely "touch proper," but the capacity for "acute" sensations, pleasant or painful; the sensations of pressure, weight, temperature, and "muscular sensations."

In speaking of this girl, her instructor said: "With regard to the sense of touch, it is very acute, even for a blind person. It is shown remarkably in the readiness with which she distinguishes persons. There are forty inmates in the female wing, with all of whom, of course, Laura is acquainted; whenever she is walking through the passageways, she perceives by the jar of the floor or the agitation of the air that some one is near her, and it is exceedingly difficult to pass her without being recognized. Her little arms are stretched out, and the instant she grasps a hand, a sleeve, or even a part of the dress, she knows the person, and lets them pass on with some sign of recognition. Her judgment of distances and of relations of place is very accurate; she will rise from her seat, go straight toward a door, put out her hand just at the right time, and grasp the handle with precision."

From her *Life and Education* it is impossible to ascertain what ability Laura possessed of distinguishing colors. Her historian says that it has been stated that she could tell the color of everything by feeling, but that this is not true. He further says that fabulous stories have been told of the power of the blind to distinguish color, but such statements could not be made of those in

the institution with which she was connected. "It is true of many totally blind that, if a number of balls of worsted of various colors are given them, and they are obliged to notice them carefully in order to use them in their proper places in work, they will rarely make a mistake. So we may give them pieces of silk, with the same result; but this does not prove that, having been told the colors in one material or fabric, they will recognize them in any other.

"We have no evidence that there is any inherent property in the color red, or blue, or yellow, which will enable the most sensitive touch to detect each in all materials offered."

**Sense of Pressure.**—When objects are laid upon the hand there is a sensation produced, which is that of *pressure*, and by the exercise of this sense we are able to distinguish differences in the weights of objects. This is true of other portions of the body as well as of the hand. Sense of pressure and tactile sensibility are not identical; indeed, portions of the body in which the latter is very acute are nevertheless very insensitive to pressure. Thus the tactile sensibility of the tip of the tongue is very highly developed, but its sense of pressure is very deficient. Kirkes says that with the tip of the tongue one cannot detect the radial pulse. While there is a marked difference between the tongue and the finger in their ability to distinguish the pulse-beats, still the writer is positive that the statement that these cannot be felt by the tongue is not true for all individuals.

It is to be borne in mind that in the investigation of the sense of pressure the muscles must not be brought into play, otherwise a new factor is involved—the muscular sense.

**Muscular Sense.**—This sense is brought into action in lifting weights, and the estimation of the weight of an object depends upon the amount of nervous energy (efferent impulses) necessary to accomplish the result. Some authorities regard it as a modification of the sense of pressure; but the two senses are undoubtedly distinct.

**Sense of Temperature.**—By this sense the difference in temperature of bodies is recognized, and it is a well-known fact that the various portions of the body are endowed with different degrees of sensibility in this regard: The hand will bear a degree of heat which would cause great pain to some other parts of the body. The sense of temperature and that of touch are entirely distinct, and this fact may readily be demonstrated by pressing firmly on a sensitive nerve until the part to which it is distributed is almost devoid of the sense of touch, when it will be found that the sense of temperature is unaffected.

Not only is the sense of temperature distinct from other sensation, but even this is so subdivided that there are *heat spots* and *cold spots*—that is, portions of the skin which are excited by heat

and cold respectively. Thus if a heated object is moved about over the skin, at some points tactile sensibility alone will be excited, while at others the object will feel distinctly hot. In like manner cold spots will be recognized by the application of a cold object. This test applied to the skin of the forearm has resulted in such a chart as is shown in Fig. 308.

**Sense of Pain.**—When the stimuli that call out the sense of touch or of temperature are excessive, the sense of pain is produced, and the other sensations are abolished; thus when a piece

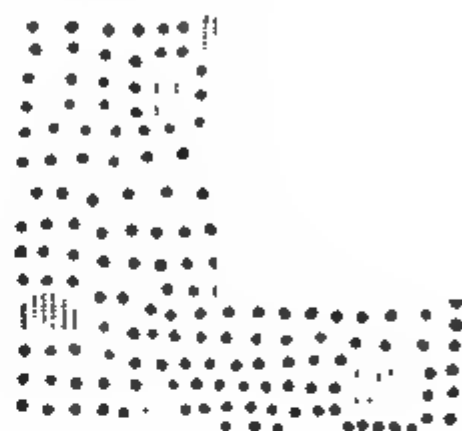


FIG. 308.—Cold and hot spots from the same part of the anterior surface of the forearm: a, cold-spots; b, hot-spots. The dark parts are the more sensitive; the hatched the medium; the dotted the feeble; and the vacant spaces the non-sensitive.

of iron very much heated burns the hand, the sensation is the same as when the iron is very cold.

Some authorities regard the sense of pain as being a distinct sensation, others as simply an exaggeration of other sensations.

**Sense of Smell.**—In the consideration of the respiratory processes the nose was described as being a part of the respiratory tract (p. 353). This is true of the lower portion of the nasal cavity, the entrance or *regio vestibularis* and the *regio respiratoria*, the rest of the lower part of the nasal cavity; the upper part, however, is more especially concerned with the function of smell, and is therefore called *regio olfactoria*. This portion of the mucous membrane is sometimes denominated *olfactory membrane*, and may be defined as that portion of the Schneiderian membrane which covers the superior and middle turbinated bones and the upper part of the septum nasi. The Schneiderian membrane lines the nasal fossæ. Before the time of Schneider, from whom the mem-



brane was named, it was thought that the secretion it forms came from the brain: he demonstrated that it came from the membrane itself. It is covered by epithelium, which, near the orifice of the nostril in the vestibule, is pavement, but elsewhere, except on the olfactory membrane, this epithelium is columnar and ciliated. In man the olfactory membrane is soft, vascular, and of a yellow color. It is covered by epithelium composed of two varieties of cells, with a superficial lamina through which the ends of the cells project. One variety, *olfactory* or *olfactorial cells*, is spindle-shaped and bipolar (Fig. 309), having a nucleus. One of the poles extends to the surface, its extremity passing through the lamina, and in amphibia, reptiles, and birds terminates in fine, hair-like filaments. It is uncertain whether these filaments exist in mammals. The other pole extends downward and is connected with one of the fibrils of the olfactory nerve, and passes through the cribriform plate of the ethmoid bone, and arborizes within one of the olfactory glomeruli (Fig. 310). The other variety of cells is the *columnar* or *sustentacular cell*. These are columnar epithelium-cells with nucleated cell-bodies at the free surface of the mucous membranes and branching processes extending downward: they are supporting cells. The *corium* of the olfactory membrane is very thick and vascular, with bundles of olfactory nerve-fibers and a large number of serous glands, *Bowman's glands*, whose ducts open upon the surface of the membrane between the epithelial cells.

FIG. 309.—Olfactory mucous membrane: *a*, sustentacular cells; *b*, olfactory cells; *c*, basal cells; *d*, submucous fibrous tissue; *e*, glands of Bowman; *f*, nerve-fibers (Leroy).

**Olfactory Nerves.**—These are about twenty in number, non-medullated, and are given off from the olfactory bulb. They pass through the cribriform plate of the ethmoid bone and are distributed to the olfactory membrane.

**Olfactory Bulb.**—This is in reality a portion of the hemispheres, and is described as "a cap superimposed upon a conical process of the cerebrum." It consists of gray and white matter, and is thus described by Schäfer: "Dorsally there is a flattened ring of longitudinal white bundles enclosing neuroglia, as in the olfactory tract; but below this ring several layers are recognized, as follows:



"1. A *white or medullary layer*, characterized by the presence of a large number of small cells ('granules') with reticulating bundles of medullated nerve-fibers running longitudinally between them.

"2. A *layer of large nerve-cells*, with smaller ones intermingled, the whole embedded in an interlacement of fibrils which are mostly derived from the cell-dendrons. From the shape of most of the large cells of this layer it has been termed the 'mitral' layer. These cells send their neurons upward into the next layer,

FIG. 310.—Diagram of the connections of cells and fibers in the olfactory bulb: *olf.c.*, cells of the olfactory mucous membrane; *olf.a.*, deepest layer of the bulb, composed of the olfactory nerve-fibers which are prolonged from the olfactory cells; *gl.*, olfactory glomeruli, containing arborization of the olfactory nerve-fibers and of the dendrons of the mitral cells; *m.c.*, mitral cells; *a.*, thin axis-cylinder process passing toward the nerve-fiber layer, *n.tr.*, of the bulb to become continuous with fibers of the olfactory tract; these axis-cylinder processes are seen to give off collaterals, some of which pass again into the deeper layers of the bulb; *n'*, a nerve-fiber from the olfactory tract ramifying in the gray matter of the bulb (Schäfer).

and they eventually become fibers of the olfactory tract and pass along this to the base of the brain, giving off numerous collaterals in the bulb as they pass backward.

"3. The *layer of olfactory glomeruli* consists of rounded nest-like interlacements of fibrils which are derived on the one hand from the terminal arborizations of the non-medullated fibers which form the subjacent layer, and on the other hand from arborizations of descending processes of the large 'mitral' cells of the layer above.

"4. *The Layer of Olfactory Nerve-fibers.*—These are all non-

medullated, and are continued from the olfactory fibers of the Schneiderian or olfactory mucous membrane of the nasal fossæ. In this mucous membrane they take origin from the bipolar olfactory cells which are characteristic of the membrane, and they end in arborizations within the olfactory glomeruli, where they come in contact with the arborizations of the mitral cells."

**Olfactory Tract.**—This structure is an outgrowth from the brain, which is in man at one period of development hollow, but later the cavity is filled with neuroglia, outside of which are bundles of white fibers, and still more external is a layer of neuroglia. There

FIG. 311.—The olfactory bulb, after Golgi and Ramón y Cajal. The granular layer is not shown.

are no nerve-cells in the tract. It lies in the *olfactory sulcus*, a depression in the under surface of the frontal lobe of the cerebrum, and terminates in the olfactory bulb. Traced backward, the tract is found to be made up of two roots, external and internal; between these is the *trigonum olfactorium*, which is sometimes called the *middle* or *gray root*, but which is in reality cortical gray matter. The external root is connected with the end of the hippocampal gyrus, and the internal with the beginning of the gyrus fornicatus.

**Functions of the Olfactory Nerves.**—The olfactory nerves are beyond all doubt the channels by which olfactory impressions reach the brain (Fig. 312). They are nerves of the special sense

of smell. The whole mucous membrane of the nose is not supplied with olfactory fibers; hence only in that part where they are present, the olfactory membrane, does the sense of smell reside. The proof that the function of these nerves is that of smell is derived from experiments upon lower animals and from observations upon man. Animals whose sense of smell is very acute have the olfactory bulbs and tracts more highly developed—that is, these structures are larger—than in those animals in which the acuteness of the sense of smell is not marked. If the tracts are destroyed, the sense of smell is abolished. Although this experi-

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FIG. 312.—Nerves of the outer walls of the nasal fossæ: 1, network of the branches of the olfactory nerve, descending upon the region of the superior and middle turbinated bones; 2, external twig of the ethmoidal branch of the nasal nerves; 3, sphenopalatine ganglion; 4, ramification of the anterior palatine nerves; 5, posterior, and 6, middle, divisions of the palatine nerves; 7, branch to the region of the inferior turbinated bone; 8, branch to the region of the superior and middle turbinated bones; 9, nasopalatine branch to the septum cut short (from Sappey, after Hirschfeld and Leveillé).

mental proof is not applicable in man, still there are cases on record in which an absence of the sense of smell during life has been found after death to have accompanied an absence of the olfactory tracts; and there are cases also of individuals whose sense of smell has been seriously impaired after injury to the tracts.

During ordinary respiration the inspired air does not pass over the olfactory membrane, but only over the lower part of the Schneiderian membrane, the respiratory portion. Hence if odors are faint, they are not detected, unless by a strong inspiration the air is carried up to and over that portion to which the olfactory nerves are distributed. If the nasal passages are closed by a catarrhal condition, the sense of smell is obtunded or may even be abolished temporarily.

It is important to distinguish between the sense of smell and general sensibility. The mucous membrane of the nose has, in common with other mucous membranes and the skin, the power to recognize such physical properties in objects as consistency, temperature, etc. Thus if a sharp instrument was to be brought in contact with this membrane, it would be recognized as sharp, but this recognition is not due to the excitation of the olfactory nerves, but to the fibers of the trigeminus. The mucous membrane is therefore supplied by two nerves, the olfactory and the fifth. One is not liable to confound sharpness with odor, but the irritating effects of certain substances are often confounded with the sense of smell, when, as a matter of fact, it is not the olfactory, but the fifth pair, which is excited. Thus if acetic acid is brought in contact with the mucous membrane of the nose, it will excite the fibers of the fifth pair and will produce an irritating effect, but it would be incorrect to say that we smelled it. If, however, vinegar was substituted for the acetic acid, we should have the irritating effect of the acetic acid it contains, and in addition the olfactory nerves would be excited by the aromatic ingredients which, with the acid, form vinegar; and it would therefore be correct to say that we smelled the vinegar.

The acuteness of the sense of smell differs in different individuals, but in most it is well marked. It has been estimated that  $\frac{1}{2000000}$  of a milligram of musk may be detected by this sense. The emanations from objects which excite the sense of smell produce this effect by stimulating the olfactory cells, and the impulses are carried by the olfactory nerves to the brain.

*Case of Julia Brace.*—A remarkable instance of the acuteness of the sense of smell is that of Julia Brace, an inmate of the Hartford Asylum, who became entirely deaf and blind at the age of four years and five months. The history of this case is given in the *Life and Education of Laura D. Bridgman*, by M. S. Lamson. This girl could select by the sense of smell her own clothes from a mass of dresses belonging to a hundred and thirty or forty persons. "She could discriminate, merely by smelling them, the recently washed stockings of the boys at the asylum from those of the girls. Among a hundred and twenty or thirty teaspoons used at the asylum she could distinguish those of the steward from those of the pupils." Her sense of touch was also acute. "By putting the eye of a cambric needle upon the tip of her tongue, she could feel the thread as it entered the eye and pressed upon her tongue, and she would thus thread the needle."

**Sense of Taste.**—The sense of taste exists to a slight degree in the middle of the dorsum of the tongue, but is especially developed in the posterior third of the dorsum. It is also present in its tip and edges and in the soft palate, but the exact area in which it resides has never been determined.

The nerves supplying the anterior two-thirds of the tongue are the lingual branch of the fifth pair, and the chorda tympani, while the posterior portion is innervated by the glossopharyngeal. Some authorities regard the glossopharyngeal as the sole gustatory nerve, and attribute to the lingual branch only tactile properties, while others hold that the fifth nerve is the true nerve of taste, and that whatever function the glossopharyngeal seems to have in this re-

FIG. 313.—Papillar surface of the tongue, with the fauces and tonsils: 1, 1, circumvallate papillæ, in front of 2, the foramen cæcum; 3, fungiform papillæ; 4, filiform and conical papillæ; 5, transverse and oblique rugæ; 6, mucous glands at the base of the tongue and in the fauces; 7, tonsils; 8, part of the epiglottis; 9, median glosso-epiglottidean fold (frænum epiglottidis) (from Sappey).

spect is derived from the fifth through anastomosis. It must be regarded as an unsettled question.

The mucous membrane of the tongue is covered with papillæ, *lingual papillæ*, of three varieties—circumvallate, conical, and fungiform.

The *circumvallate papillæ* (Fig. 313), about twelve in number, form the boundary between the anterior two-thirds and the posterior

third of the tongue. They are arranged in V shape, the apex being backward. In these papillæ are the *taste-buds*, and with these the glossopharyngeal nerve is in communication.

The **conical papillæ**, so called from their conical-pointed epithelial caps, are present throughout the rest of the lingual mucous membrane. Some of these, *filiform papillæ* (Fig. 315), possess fine epithelial filaments in the cap.

The **fungiform papillæ** (Fig. 316) are larger than the conical and scattered among them. They are highly vascular.

Between the superficial lingual muscles are tubular glands, whose ducts open on the surface. These are principally mucous

Epithelium.

Taste-buds.

Groove surrounding  
papilla.

FIG. 314.—Longitudinal section of a human circumvallate papilla;  $\times 20$  (Böhm and Davidoff).

glands; but some are serous, *glands of Ebner*, and these latter open into the fossæ of the circumvallate papillæ; their secretion is regarded by Ebner as assisting in the distribution of substances to be tasted over the taste-area.

**Taste-buds** (Fig. 317).—These occur in both the circumvallate and fungiform papillæ, and also in the epithelium of the general mucous membrane of the tongue, especially in that of the dorsum and sides. They are also found on the under surface of the soft palate and on the epiglottis. They are thus described by Schäfer: "The taste-buds are ovoid clusters of epithelium-cells which lie in cavities in the stratified epithelium. The base of the taste-bud rests upon the corium of the mucous membrane, and receives a

branch of the glossopharyngeal nerve; the apex is narrow and communicates with the cavity of the mouth by a small pore in the superficial epithelium—*gustatory pore*.

“The cells which compose the taste-buds are of two kinds, viz.: 1. The *gustatory cells*, which are delicate fusiform or bipolar cells composed of the cell-body or nucleated enlargement, and of two processes, one distal, the other proximal. The distal process is nearly straight, and passes toward the apex of the taste-bud,

Papilla filiformis.

Tongue epithelium.

Connective-tissue papilla.

Mucosa.

Basal epithelial layer.

FIG. 315.—From a cross-section of the human tongue, showing short, thread-like papillæ (filiform),  $\times 140$  (Böhm and Davidoff).

where it terminates in a small, highly refracting cilium-like appendage which projects into the bottom of the pore above mentioned. The proximal process is more delicate than the other, and is often branched and varicose. The nerve-fibers take origin in ramifications among the gustatory cells (Retzius).

“2. The *sustentacular cells* (Fig. 318).—These are elongated cells, mostly flattened, and pointed at their ends; they lie between the gustatory cells, which they thus appear to support, and in addition they form a sort of envelope or covering to the taste-bud.

Between the cells of the taste-buds lymph-corpuscles are often seen, having probably wandered hither from the subjacent mucous membrane."



FIG. 316.—Fungiform papilla from human tongue (Huber).

Fig. 319 shows the nerve-endings in the taste-buds.

The fact that the general sensibility of the tongue may be lost and the sense of taste remain indicates that the channels for the



FIG. 317.—Longitudinal section of foliate papilla of rabbit, showing taste-buds (Huber).

transmission of these two sensations are different. It may be well again to call attention to the necessity for making a distinction between what may be tasted and what may be smelled, between savors and flavors. The sense of taste gives cognizance of the



		Process of	
		neuro-epi-	
Epithe-	Nerve-	thelial	Taste-
lium.	fibrils.	cell.	pore.

FIG. 318.—Schematic representation of a taste-goblet (partly after Hermann).

qualities *sweet, acid, bitter, and saline*; but to speak of an oily taste is incorrect: such a quality appeals to general sensibility only. The tip of the tongue is most sensitive to sweet tastes, the sides to acid, and the back to bitter.

**Conditions of the Sense of Taste.**—That the sense of taste may be exercised requires the presence of certain conditions, one of which is that the substance must be in a state of solution or be soluble in the saliva. Insoluble substances are tasteless: for this reason calomel is especially suitable as a cathartic for children. Another condition is that the mucous membrane of the mouth must be moist. When the mouth is dry and substances not already in a state of solution are taken in, there is no saliva present to dissolve them; consequently they are not tasted. This absence of taste is very marked in the parched condition of the mouth occurring during fevers.

FIG. 319.—Nerve-endings in taste-buds: *n*, nerve-fibers of taste-buds, *b*; *i*, ending of fibrils within taste-bud; *p*, ending in epithelium between taste-buds; *s*, surface epithelium (G. Retzius).

To excite the sense of taste, sapid substances must pass by osmosis into the papillæ of the mucous membrane and there stimulate the terminal filaments of the nerves which preside over this sense. An important agent in causing this absorption is the

movement of the tongue. It is a matter of common observation that if sapid substances are simply placed on the tongue, the sense of taste is not excited; but if the tongue is pressed against the roof of the mouth, absorption is promoted and the gustatory qualities are at once recognized.

It is to be noted also that a savor persists for a certain length of time, and that if it is desired to determine the comparative qualities of different substances by the sense of taste, there must either be intervals between the tests or something must be used to obliterate the taste of the first before the second is taken into the mouth. It is also noteworthy that some savors so powerfully impress the taste-organs that others subsequently fail to make any impression. This principle is made practical use of in rendering disagreeable medicines tasteless. Thus a few cloves eaten before taking a dose of castor oil will render the latter far less nauseous; a mouthful of brandy will have the same effect.

**Sense of Sight.**—The eyes are situated in the *orbits*, cavities formed by the frontal, sphenoid, ethmoid, superior maxillary, malar, lacrimal, and palate bones. Each eye is embedded in fat and enclosed in a serous sac, the *capsule of Tenon* or *tunica vaginalis oculi*. The transverse diameter of the eye is about 2.5 cm., while the anteroposterior and vertical diameters are about 2.25 cm. each.

**Coats or Tunics** (Fig. 320).—These are 3 in number: (1) Sclerotic and cornea; (2) choroid, ciliary processes, iris, and ciliary muscle; and (3) retina.

**Sclerotic.**—This tunic forms the external coat of the eye for its posterior five-sixths, the anterior sixth being formed by the cornea. The sclerotic is opaque, and is made up of dense fibrous tissue with elastic fibers and connective-tissue corpuscles, and the white color of its visible external surface covered by conjunctiva causes this portion to be known as the *white of the eye*. The internal surface is lined by connective tissue, in which are brown pigment-cells, *lamina fusca*. This inner surface is grooved, and in these grooves lie the ciliary nerves. Posteriorly and on the nasal side the optic nerve pierces the sclerotic, which in this part is characterized by small openings, through which the fibers composing the optic nerve pass. This sieve-like structure has given to the sclerotic at this point the name *lamina cribrosa*. The largest of these openings, *porus opticus*, is in the middle of the lamina, and through it passes the *arteria centralis retinae* (Fig. 328, A). Encircling the lamina cribrosa are openings in the sclerotic through which pass the ciliary vessels and nerves. Supplying the sclerotic itself, nerves have not been demonstrated.

**Cornea.**—This structure is transparent, and its relation to the sclerotic has been compared to that of a watch-crystal to the

watch itself. It is the segment of a smaller sphere than the sclerotic. Its anterior surface is convex and covered by conjunctiva, its posterior surface concave, the curvature being less in old age. It is composed of four layers (Fig. 321): (1) *Stratified epithelium*, next to the conjunctiva. (2) A thin layer of connective tissue, *membrane of Bowman*. (3) Fibrous connective tissue, *proper substance* of the cornea, which is made up of fibers arranged in lamellæ, those of each of the sixty bundles being at right angles with those of the lamellæ above and below it. Between the

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FIG. 320.—Schematic diagram of the eye: a, vena vorticosæ; b, choroid; l, lens (after Leber and Flemming).

lamellæ, and connecting them, is a cement substance, and in this are the stellate *corneal spaces*, each of which contains a *corneal corpuscle*, which gives off branches that form with the processes of other corpuscles a continuous network. This third layer is of the same character as the sclerotic coat, and is continuous with it. (4) *Membrane of Descemet* or *Demours*, an elastic layer which, near the junction of the cornea with the iris, separates into fibers, *ligamentum pectinatum*. Some of these exist in the iris as its *pillars*. The fourth layer is covered by pavement epithelium, *epithelium of Descemet's membrane*. This epithelium forms, there-

fore, the most posterior portion of the cornea, and inasmuch as the space directly behind the cornea is the *anterior chamber*, this epithelium forms the anterior boundary of this space. These epithelial

Corneal  
epithelium

Basal cells.

Anterior  
elastic  
membrane

Substantia  
propria.

FIG. 321.—Section through the anterior portion of human cornea;  $\times 500$  (Böhm and Davidoff).

cells are continuous with those covering the anterior surface of the iris. The cornea contains no blood-vessels, these ending in the form

Sclera.

Lamina supra-  
choroidea.

Lamina vascu-  
losa Hallerl.

Lamina chorio-  
capillaris.  
Glassy layer.

FIG. 322.—Section through the human choroid;  $\times 130$  (Böhm and Davidoff).

of loops at its circumference. Nor are there distinct lymphatics, though the channels which lodge the nerves are believed to serve this purpose. Branches of the ciliary nerves are supplied to it,

varying in number from twenty-four to forty-five, according to different authorities. These nerves terminate in the *subepithelial plexus*, beneath the superficial epithelium, from which fibers pass to the cells themselves, forming the *intra-epithelial plexus*.

*Choroid*.—This vascular and pigmented structure forms the posterior five-sixths of the second tunic of the eye. Its anterior boundary is the *ciliary ligament* formerly so called, but also known as the *ring muscle of Müller*; it is composed of the circular fibers of the ciliary muscle. Anterior to this is the iris. At the anterior margin of the choroid are the ciliary processes. The inner surface of the choroid is in contact with the retina.

The choroid is composed of three layers: (1) *lamina supra-choroidea* (Fig. 322), the most external, consisting of connective tissue, elastic fibers, pigment-cells, and lymph-corpuses. It is

I

12-

10-

7.

7

16.

Sclera.

Processus ciliares.

FIG. 323.—Meridional section of the human ciliary body;  $\times 20$  (Böhm and Davidoff).

in contact with the lamina fusca of the sclerotic. (2) *Vascular layer*; this is spoken of as the *choroid proper*; here are the blood-vessels of the choroid, consisting externally of branches of the short ciliary arteries, and veins arranged in a vorticose, whorled, or star-like form, constituting the *venae vorticosae*, which converge to form four or five main veins; between these vessels are stellate pigment-cells. The inner portion of the vascular layer is the *choriocapillaris* or *tunica Ruyschiana*, a plexus of fine capillaries from the short ciliary vessels. (3) The most internal portion of the choroid is the *lamina vitrea*, *glassy layer*, or *membrane of Bruch*, a thin membrane, transparent, and ordinarily described as structureless, although Kölliker considers it to have a fibrous structure. This is in contact with the pigmentary layer of the retina.

The arteries of the choroid are the short ciliary and the recur-

rent branches of the long and the anterior ciliary. Its nervous supply is the long and short ciliary nerves.

*Ciliary Processes* (Fig. 323).—The vascular layer of the choroid with the lamina vitrea is arranged anteriorly in folds—the ciliary processes. These fit into corresponding folds of the suspensory ligament of the crystalline lens. Their number varies from sixty to eighty; some being about 0.25 cm. in length, others shorter. In structure they are like the choroid, except that their blood-vessels are larger and are longitudinally arranged. On their posterior surface are pigment-cells, as there are also in the processes themselves.

*Iris*.—This is a muscular and vascular structure in front of the crystalline lens and behind the cornea. In its center is a circular opening—the *pupil*. Its structure is not unlike that of the choroid, and on its anterior surface are pigment-cells, the color of

2

4

FIG. 324.—Crystalline lens and suspensory ligament or zonula: 1, lens; 2, posterior, and 3, anterior portion of zonula; 4, its insertion into the pre-equatorial region. The black rays are lines of pigment torn from the ciliary processes, and belong in reality to the ciliary portion of the retina (Testut).

whose pigment differs in different individuals. Its posterior surface is covered with a layer of pigmented epithelial cells, the *uvea*, which is continuous with those of the *pars ciliaris retinae*.

The iris is composed of four layers: (1) Most anteriorly is a layer of cells which is continuous with the epithelium of Descemet's membrane, and in these there is pigment. (2) The *stroma*; this consists of fibrous tissue, the fibers of which at the margin of the pupil are circular, elsewhere, and for the most part, radiating. Among these fibers are branched cells, containing pigment in persons whose eyes are dark, while in light eyes the pigment is absent. (3) A *muscular* layer consisting of the *sphincter pupillae*, which is composed of involuntary fibers circularly arranged around the pupil, and having a width of about 0.08 cm., and of the *dilator pupillae*, composed of fibers arranged in a radiating direction. (4) The *pigmentary* layer on the posterior surface of the

iris. It is this pigment which, as seen through the layers of the iris anterior to it, gives the color to light eyes, while in those having dark eyes there is, besides, pigment in the fibrous tissue of the stroma and on the anterior surface of the iris. The albino is characterized by the colorless iris, in which no pigment is present.

The arteries which supply the iris are branches of the long and anterior ciliary, which together form the *circulus iridis major* and *minor*, the former being an anastomotic ring at the outer margin of the iris; the latter, a similar one near the pupil.

The nervous supply of the iris is derived from the ciliary ganglion and from the nasal branch of the ophthalmic division of the fifth nerve through the long ciliary. The branches from the ciliary ganglion contain fibers of the third nerve, which supply the circular muscular fibers or sphincter pupillæ, and also sympathetic fibers, which are distributed to the radiating fibers or dilator pupillæ.

*Membrana Pupillaris.*—

The pupil during fetal life, until about the seventh or eighth month, is closed by a membrane. At this time it begins to be absorbed, and the absorption is almost entirely complete at birth.

*Ciliary Muscle* (Fig. 323).

—Like the muscular fibers of the iris, this muscle is also of the unstriped variety. Its width is about 0.3 cm., and it consists of two parts, a ra-

FIG. 325.—Injected blood-vessels of the human choroid and iris;  $\times 7$  (Böhm and Davidoff).

diating and a circular. The *radiating* or *radial* fibers are the more numerous, and have their origin at the junction of the cornea and sclerotic, *sclerocorneal junction*, and passing backward are attached to the choroid opposite the ciliary processes. Waldeyer states that one bundle is attached to the sclerotic. Internal to these are the *circular* fibers, running around the attachment of the iris, called *circular ciliary muscle*, *ring muscle of Müller*, and formerly *ciliary ligament*. These fibers are said to be most marked in hypermetropic eyes.

*Ciliary Body.*—In this term are included the ciliary muscle and the ciliary processes.

*Retina.*—This is the most internal of the tunics of the eye,

FIG. 326.—The normal eye-ground as seen with the ophthalmoscope: *n*, optic nerve-head; *m*, macula; *a*, retinal artery; *v*, retinal vein (Pyle).

and is divided into two parts: (1) *Pars optica retinae*, which extends as far forward as the ciliary body, where it ends in an



FIG. 327.—Section through human macula lutea and fovea centralis;  $\times 150$ . As a result of treatment with certain reagents, the fovea centralis is deeper and the margin more precipitous than during life (Böhm and Davidoff).

irregular margin, *ora serrata*; (2) *pars ciliaris retinae*, composed of the fibrous stroma of the retina with the pigment-layer, with-



out the nervous elements present in the pars optica. This portion passes forward as far as the outer margin of the iris.

*Macula Lutea* (Figs. 326, 327).—At the center of the retina posteriorly, and at the posterior extremity of the axis of the eye,

FIG. 328.—Diagrammatic representation of the retina.

is the macula lutea, *yellow spot of Sömmerring*, or *limbus luteus*, having a diameter of from 1 to 2 mm., an elevated spot in the retina where the sense of sight is most acute; in its center is a depression, the *fovea centralis*, whose diameter is from 0.2 mm.



FIG. 329.—Schematic diagram of the retina, according to Ramón y Cajal: the line *a*, after passing through a Müller's fiber, crosses a bipolar rod-cell, then two bipolar cone-cells, and finally ends in the body of a bipolar cone-cell *a'*; Nerve-fiber layer; *b*, ganglion-cell layer; *c*, inner molecular layer; *d*, spongioblast; *e*, nucleus of Müller's fiber; *f*, inner nuclear layer; *g*, bipolar cone-cell; *h*, outer molecular layer; *i*, outer nuclear layer; *k*, cone; *l*, rod; *m*, centrifugal nerve-fiber; *n*, impressions on Müller's fiber of elements of outer nuclear layer; *o*, fiber basket of Müller's fiber; *p*, diffuse spongioblast; *q*, large horizontal cell; *r*, bipolar cell.

to 0.4 mm. At the fovea the retina is so thin that the color of the choroid can be seen through it, and hence it has somewhat the appearance of an opening, and was formerly called *foramen of Sömmerring*. For further discussion of the macula the reader is referred to p. 553.

*Porus Opticus* (Fig. 328).—About 3 mm. to the nasal side of the macula lutea, and about 1 mm. below its level, is the *optic disk*, the entrance of the optic nerve; inasmuch as vision is absent at

Layer of nerve-  
fibers.  
Ganglion-cell layer.  
  
Inner molecular  
layer.  
  
Inner nuclear layer.  
  
Outer molecular  
layer.  
  
Outer nuclear layer.  
  
Ext. limiting mem-  
brane.  
Inner segment of  
rod.  
Inner segment of  
cone.  
Outer segment of  
cone.  
Outer segment of  
rod.

FIG. 330.—Section of the human retina;  $\times 700$  (Böhm and Davidoff).

this point, it is called the *blind spot*. At its center, through the *porus opticus*, enters the *arteria centralis retinae*. As the retina is somewhat elevated at the blind spot, this portion of it has also received the name of *colliculus nervi optici*.



FIG. 331.—Section through point of entrance of human optic nerve;  $\times 40$  (Böhm and Davidoff).

The *arteria centralis retinae* is a branch of the ophthalmic artery, and, after piercing the *porus opticus*, it divides into four or five branches which run between the hyaloid membrane and the

nervous layer of the retina, later passing into the retina and ending in a capillary plexus external to the inner nuclear layer. During fetal life a small artery passes forward through the vitreous to the posterior surface of the capsule of the lens. In the fovea centralis there are no blood-vessels, and very few in the rest of the macula lutea.

*Minute Structure of the Pars Optica Retinæ* (Figs. 329, 330, 331).—The pars optica of the retina consists of ten layers, arranged in the following order, beginning with the most internal—*i. e.*, with the layer next to the hyaloid membrane which encloses the vitreous humor—and ending with the most external, the pigmentary layer which is contiguous to the lamina vitrea of the choroid:

1. Membrana limitans interna;
2. Nerve-fiber layer;
3. Ganglionic layer;
4. Inner molecular layer;
5. Inner nuclear layer;
6. Outer molecular layer;
7. Outer nuclear layer;
8. Membrana limitans externa;
9. Layer of rods and cones;
10. Pigmentary layer.

1. *Membrana Limitans Interna*.—This is a transparent membrane, and a part of the supporting connective tissue of the retina, or the fibers of Müller, in connection with which it is again referred to (p. 553).

2. *Nerve-fiber Layer*.—This is sometimes described as the *fibrous* layer. It is composed, however, of nerve-fibers, and not of so-called fibrous tissue. The fibers of which it is composed are those of the optic nerve, and, as this enters the eye from behind, these fibers must pass through all the layers, excepting the membrana limitans interna, in order to reach the nerve-fiber layer. It will be remembered that the fibers of the optic nerve pass through the lamina cribrosa of the sclerotic; at this part of their course their medullary sheaths disappear and they become simple axis-cylinders, and as such they traverse the choroid and the retina until they reach the nerve-fiber layer, where they radiate from the point of entrance and terminate, some in the cells of the third or ganglionic layer, while others pass through the third and fourth layers and terminate in the fifth or inner nuclear layer. The nerve-fiber layer is thickest at the point of entrance of the optic nerve, and, gradually becoming thinner, ends at the ora serrata—*i. e.*, anterior to this, nerve-fibers are not found in the retina. Or this may be stated in another way, by saying that nerve-fibers are found in the pars optica retinæ, but not in the pars ciliaris retinæ.

3. *Ganglionic Layer*.—This is called also *vesicular layer* and *layer of nerve-cells*, and consists of a single layer of large ganglion-

cells. In the macula lutea the cells are smaller, and lie in several layers. The shape of these ganglion-cells is peculiar, resembling somewhat those of Purkinje in the cerebellum. The portion which is in contact with the nerve-fiber layer is rounded, and from it is given off an axis-cylinder process which is continuous with one of the axis-cylinders which make up the nerve-fiber layer. From the opposite side of each cell is given off a thick process which branches, the branches ending in arborizations at different levels in the fourth or inner molecular layer.

4. *Inner Molecular Layer*.—This is called also *inner granular layer*, by reason of its granular appearance, and also *reticular layer*. It is relatively thick, and consists of a reticulum of nerve-fibers with interspersed granules, of processes of the cells of the ganglionic layer, and of those of the inner nuclear layer.

5. *Inner Nuclear Layer*.—The characteristic elements of this layer are bipolar nerve-cells in which are large nuclei; these cells are called *inner granules*. The process of each of these cells which passes inward terminates in arborizations in the inner molecular layer; the process that passes outward terminates in a similar manner in the outer molecular layer. There are two kinds of these bipolar cells: (1) Rod-bipolars and (2) cone-bipolars. The *rod-bipolars* are connected externally with the rods of the retina, and internally with the rods of the ganglionic layer. The *cone-bipolars* are connected with the cones of the retina externally, while internally they ramify in the middle of the inner molecular layer.

In addition to bipolar cells there are *amacrine-cells*, so called because they lack long processes, although from some of them axis-cylinder processes are given off which may extend into the nerve-fiber layer. The bodies of these cells are often partly in the inner molecular layer, and they are sometimes called *spongioblasts of the inner molecular layer*. From them are given off branching processes or dendrons which pass into the inner molecular layer.

*Horizontal cells of Cajal* or *spongioblasts of outer molecular layer* are cells in this layer which send processes into the outer molecular layer.

6. *Outer Molecular Layer*.—This is a thin layer, and consists of the arborizations of the inner nuclear layer, of the rod- and cone-fibers, and of the horizontal cells of Cajal. Schäfer states that up to this point—i. e., including the outer molecular layer—the retina may be regarded as composed of nervous elements, but beyond it is to be considered as formed of modified epithelium-cells.

7. *Outer Nuclear Layer*.—In this layer are found cells characterized by transverse striations, passing off from which externally are processes connected with the rods of the ninth layer, by reason

of which arrangement they are called *rod-granules*. These granules also give off processes which pass in an inward direction and terminate in the outer molecular layer. In the outer nuclear layer are also *cone-granules*; these are connected with the cones of the ninth layer externally, and internally by a thick process which becomes bulbous, the so-called *cone-foot*; they terminate in fine fibers in the outer molecular layer.

8. *Membrana Limitans Externa*.—This is, together with the *membrana limitans interna* and the fibers of Müller, a part of the supporting structure of the retina. Indeed, some authorities include neither of these membranes in the list of layers which compose the retina, and hence describe it as made up of eight rather than of ten layers.

9. *Layer of Rods and Cones*.—This is called also *Jacob's membrane* and *bacillary layer*. It is characterized by the presence of rods and cones, of which the former are much more numerous, taking the retina as a whole. Relatively the cones are more numerous at the back of the retina, but less so in the anterior part.

*Rods*.—A rod is a solid body set perpendicularly to the surface at whatever part of the retina it may be. It is made up of an outer and an inner portion, the two being cemented together. The outer portion is cylindrical and characterized by transverse striæ; it has during life a purplish-red color. The inner portion has striæ longitudinally arranged. This portion is slightly bulged, and becomes stained with carmine or iodine, while the outer portion does not take the stain.

*Cones*.—Each is conical in form, with its base lying on the *membrana limitans externa*. The apex is tapering. Like the rods, each cone is made up of an outer and an inner portion; the outer conical apex presenting transverse striæ, the inner portion being striated longitudinally. Both rods and cones present a granular appearance near the *membrana limitans externa*.

Schäfer describes the outer nuclear layer and the layer of rods and cones as one, under the name *sensory or nerve-epithelium of the retina*, inasmuch as their elements are continuous through the two layers. He says: "The elements of which this nerve-epithelium consists are elongated, nucleated cells of two kinds. The most numerous, which we may term the *rod-elements*, consist of peculiar rod-like structures (rods proper) set closely side by side, and each of which is prolonged internally in a fine varicose fiber (rod-fiber) which swells out at one part of its course into a nucleated enlargement, and ultimately ends (in mammals) in a minute knob within the outer molecular layer, where it is embedded in the ramifications of the dendrons of the rod-bipolars. The rod proper consists of two segments, an outer cylindrical and transversely striated segment, which during life

has a purplish-red color, and an inner slightly bulged segment, which in part of its length is longitudinally striated. The nucleus of the rod-element often has, in the fresh condition, a transversely shaded aspect. The *cone-elements* are formed of a conical tapering external part, the *cone proper*, which is directly prolonged into a nucleated enlargement, from the farther side of which the *cone-fiber*, considerably thicker than the rod-fiber, passes inward, to terminate by an expanded arborization in the outer molecular layer; here it comes into relation with a similar arborization of dendrons of a cone-bipolar. The cone proper, like the rod, is formed of two segments, the outer of which, much the smaller, is transversely striated, the inner, bulged segment being longitudinally striated. The inner ends of the rod- and cone-fibers come, as already stated, in contact with the peripheral arborizations of the inner granules, and through these elements and their arborizations in the inner molecular layer a connection is brought about with the ganglionic cells and nerve-fibers of the innermost layers. There appears, however, to be no anatomic continuity between the several elements, but merely an interlacement of ramified fibrils.

10. *Pigmentary Layer*.—This layer is called also *tapetum nigrum*, and consists of a single layer of hexagonal, pigmented cells in contact with the choroid. These cells send offsets inward between the rods. The pigment is in the form of minute crystals, and when the cells have been exposed to light for a considerable time they are found in the filaments just described as extending between the rods. It is supposed that the function of these pigment-granules is to restore the purple coloring-matter which has been bleached by prolonged exposure to light. In the horse and many carnivora these cells contain no pigment.

*Fibers of Müller*.—The layers of the retina between the internal and external limiting membranes are traversed by long, stiff cells, the *fibers of Müller*. At their bases they expand, and the tissue joining these expanded bases forms the *membrana limitans interna*. At the outer nuclear layer the fibers branch and form a fenestrated tissue supporting the fibers and nuclei of the rod- and cone-elements. At the junction of the outer nuclear and bacillary layers the fibers form the *membrana limitans externa*, from which sheaths pass around the bases of the rods and cones. In that portion of the fiber which lies in the inner nuclear layer is an oval nucleus. The arrangement of these fibers of Müller and the limiting membranes has been well described "as columns between a floor and a ceiling."

*Macula Lutea* (Figs. 326, 327).—The retina at the yellow spot, except at the fovea centralis, a part of the macula lutea, is thicker than elsewhere; the middle of the fovea is the thinnest part of the retina. The ganglion-cells are more numerous in the macula, as are the cones when compared with the rods. In the fovea the rods

are absent, and the cones are long and slender. This portion of the retina consists of but little else than cones and the outer nuclear layer; the cone-fibers are very distinct and nearly horizontal.

*Pars Ciliaris Retinæ.*—At the ora serrata the pars optica retinæ terminates, and the pars ciliaris retinæ begins. It consists of two layers: An external layer of pigment-cells which are the continuation of the tapetum nigrum, and an internal, of columnar cells with oval nuclei, modified fibers of Müller. The pigmented epithelium is continuous with the uvea of the iris.

The sensory epithelium receives its nourishment from the blood-vessels of the choroid.

*Anterior and Posterior Chambers.*—The *anterior chamber* is that portion of the cavity of the eye situated between the cornea and the iris; the *posterior chamber*, the space between the iris in front; and the capsule of the lens, the suspensory ligament and the ciliary processes behind. Inasmuch as the iris is in contact with the capsule for the greater part of its extent, this “chamber” is exceedingly small, and hardly deserves the name. In fetal life these two chambers are separated by the membrana pupillaris, but about the seventh or eighth month, when the membrane begins to be absorbed, they become one cavity, and are filled with *aqueous humor* (p. 556). Some authorities describe the cavity containing the vitreous under the name “posterior chamber.”

*Vitreous Body.*—This is called also *vitreous humor*. It is a transparent, jelly-like material which fills the cavity of the retina and is enclosed in a delicate membrane, the *hyaloid membrane*. At the pars ciliaris retinæ this membrane splits into two layers, an anterior and a posterior. The anterior layer becomes the suspensory ligament of the lens, while the posterior passes behind the lens and covers the anterior portion of the vitreous; at this part there is a depression in the vitreous in which the lens lies. In the vitreous are found fibers and some cells, the bodies of which contain large vacuoles and give off long and varicose processes. Through its center in fetal life runs a small artery from the arteria centralis retinæ to the capsule of the lens, but in the adult this is a simple channel, *canal of Stilling*, which is lined by a portion of the hyaloid membrane.

*Crystalline Lens* (Fig. 332).—The lens is a transparent body, biconvex in form, the convexity being greater posteriorly than anteriorly. Its transverse diameter is about 0.8 cm., and its anteroposterior diameter about 0.6 cm. It consists of concentric layers or laminæ; those that are centrally situated form the nucleus, and are harder than the external, which are relatively soft. If the lens is boiled or hardened in alcohol, these laminæ may be peeled off like the coats of an onion. The laminæ are composed of long fibers with serrated edges, which fit into corresponding serrations of adjoining fibers. When cut transversely,



the fiber is seen to be a hexagonal prism. The superficial fibers contain nuclei, giving to the external layer the name *nucleated layer*. The fibers are developed from epithelium-cells. The centers of the anterior and posterior surfaces are the *poles*, and the margin of the lens, where these surfaces meet, is the *equator*. During fetal life the lens is nearly spherical, not very transparent, and quite soft in consistence; in adult life its posterior surface is more convex than the anterior, and it is transparent. Its consistence has already been described. In old age its convexity and transparency are diminished and its density increased.

*Capsule of the Lens.*—This, like the lens, is transparent; it is structureless and elastic. At the front and the sides of the capsule on its inner surface is a layer of cubical epithelium, the *epithelium of the capsule*. These cells are elongated at the margin of the lens and become lens-fibers. This epithelium is absent from the posterior surface. The suspensory ligament is attached to the capsule around its circumference. Anteriorly the capsule and the border of the iris are in contact; at the circumference they are slightly separated, the space thus left being the posterior chamber.

FIG. 332.—Crystalline lens: *A*, longitudinal fibers; *a*, anterior capsule; *b*, anterior epithelium; *c*, lens-fibers. *B*, posterior surface view of anterior epithelium (Leroy).

*Suspensory Ligament.*—This is the anterior part of the hyaloid membrane which divides into two layers at the pars ciliaris retinæ. Its anterior surface is arranged in folds, in the depressions of which the ciliary processes lie. From these processes the ligament passes to the capsule of the lens. Its function is to assist in retaining the lens in position.

*Chemistry of the Eye.—Cornea.*—An analysis of the cornea shows that it consists of the following ingredients: Water, 75.8 per cent.; collagen, 20.4 per cent.; other organic matter, 2.8 per cent.; and ash, 1 per cent.

*Retina.*—This tunic has been analyzed in geese, with the following result:



Water . . . . .	86	to	89 per cent.
Solids . . . . .	14	"	11 "
Proteids (globulin coagulating at 50 per cent., albumin, and mucin) . . . . .	4	"	6 "
Gelatin . . . . .	18	"	17 "
Cholesterin . . . . .	0.8	"	0.8 "
Lecithin . . . . .	1	"	2.9 "
Fat . . . . .	0.05	"	0.5 "
Salts . . . . .	0.7	"	1.2 "

*Retinal Pigments.*—The black retinal pigment is *fuscin*, and is practically identical with the pigment of the iris and choroid. It belongs to the group of pigments called *melanins*, and differs but little if at all from the coloring-matter in the skin of negroes and in melanotic tumors. Fuscin contains iron, but it is still undecided whether it is derived from hemoglobin or not.

*Rhodopsin* or *visual purple* is the pigment in the outer portion of the retinal rods; it bleaches out when exposed to light, and is supposed to be derived from fuscin. The chemistry of this pigment is undetermined. Of the yellow pigment characteristic of the macula lutea but little is known.

*Aqueous Humor.*—This fluid is lymph. Its analysis is as follows :

Water . . . . .	98.687 per cent.
Solids . . . . .	1.818 "
Proteids { Fibrinogen Serum-albumin Serum-globulin } . . . . .	0.122 "
Extractives . . . . .	0.421 "
Inorganic salts . . . . .	0.77 "
Sodium chlorid . . . . .	0.689 "

*Vitreous Humor.*—From the hyaloid membrane gelatin may be obtained, also mucoid and a small amount of proteid.

*Crystalline Lens.*—The following is the analysis of the lens :

Water . . . . .	63.5 per cent.
Solids . . . . .	36.5 "
Proteids . . . . .	34.98 "
Lecithin . . . . .	0.28 "
Cholesterin . . . . .	0.22 "
Fats . . . . .	0.29 "
Salts . . . . .	0.82 "

The proteid is a globulin called *crystallin*—or, rather,  $\alpha$ -crystallin and  $\beta$ -crystallin; there is also a small amount of albumin in the lens. In the "proteids" is a considerable amount—about 48 per cent.—of an albuminoid substance, insoluble in water and saline solutions.

**Ocular Muscles** (Figs. 333, 334).—The muscles which move the eyeball are 6 in number: (1) Superior rectus; (2) inferior rectus; (3) internal rectus; (4) external rectus; (5) superior oblique; (6) inferior oblique.

*Superior Rectus.*—Its *origin* is from the upper margin of the optic foramen and the fibrous sheath of the optic nerve; its *insertion* is into the sclerotic, about 0.6 cm. from the margin of the cornea. *Nerve-supply* is from the oculomotorius.

*Inferior Rectus.*—Its *origin* is, in common with the internal rectus, from the *ligament or tendon of Zinn*; this is an aponeurosis which is attached around the circumference of the optic foramen, with the exception of the upper and lower parts; its *insertion* is

FIG. 333. Ocular muscles viewed after removal of lateral wall of orbit: *a*, eyeball; *b*, optic nerve; *c, c'*, eyelids; *d*, maxillary sinus; *e*, pterygoid plate; *f*, foramen rotundum; *g*, roof of orbit; *h*, frontal sinus; *i*, supra-orbital nerve; *k*, septum orbitale; 1, levator palpebræ superioris; 2, 3, superior and inferior recti; 4, 4', portions of the cut external rectus; 5, internal rectus; 6, inferior oblique; 7, insertion of superior oblique; 8, annular ligament of tendon of Zinn (Testut).

into the sclerotic, about 0.6 cm. from the cornea. *Nerve-supply* is from the oculomotorius.

*Internal Rectus.*—Its *origin* is from the ligament of Zinn; its *insertion*, into the sclerotic, about 0.6 cm. from the cornea. *Nerve-supply* is from the oculomotorius.

*External Rectus.*—Its *origin* is by two heads, the upper from the outer margin of the optic foramen, and the lower from the ligament of Zinn and a bony process at the lower margin of the sphenoidal fissure; its *insertion* is into the sclerotic, about 0.6 cm.

from the margin of the cornea. *Nerve-supply* is from the abducens.

*Superior Oblique*.—Its *origin* is from above the inner margin of the optic foramen; thence it passes to the inner angle of the orbit, where it terminates in a rounded tendon which plays through a fibrocartilaginous ring. It passes under the superior rectus, and

FIG. 334.—Ocular muscles of right side, viewed from above, after removal of roof of orbit: A, frontal bone; B, section of great wing of sphenoid; C, section of malar bone; D, anterior clinoid process; E, optic nerve; 1, superior rectus; 2, superior oblique muscle with its pulley (2') and its insertion into the eyeball (2''); 3, internal rectus; 4, external rectus; 5, common origin (ligament of Zinn) of muscles; 6, cut tendon of levator palpebræ; 7, 7', 7'', palpebral expansion of same; 8, insertion of inferior oblique; 9, intra-orbital cushion of fat; 10, orbicularis palpebrarum (Testut).

its *insertion* is into the sclerotic, between the superior rectus and the external rectus, midway between the cornea and the optic nerve. *Nerve-supply* is from the trochlearis.

*Inferior Oblique*.—Its *origin* is from the orbital plate of the superior maxilla, external to the lacrimal groove for the nasal duct; its *insertion* is into the sclerotic, between the superior rectus

and the external rectus, behind the insertion of the superior oblique. *Nerve-supply* is from the oculomotorius.

*Functions of the Ocular Muscles* (Figs. 335, 336).—The *superior rectus* turns the eye upward and inward; when the eye is turned directly upward this is brought about by the conjoint

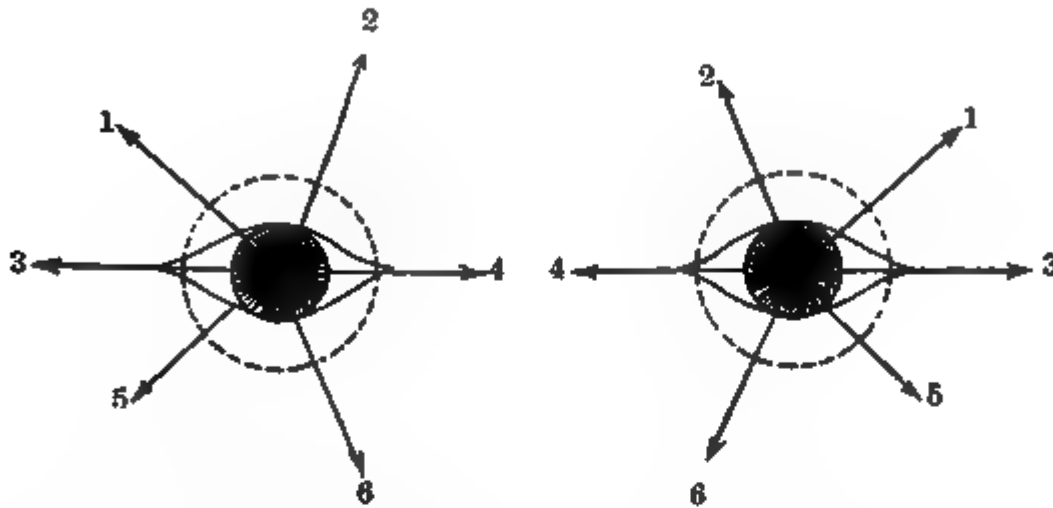


FIG. 335.—Movements of the eyeballs: 1, inferior oblique; 2, superior rectus; 3, external rectus; 4, internal rectus; 5, superior oblique; 6, inferior rectus.

action of the superior rectus and the inferior oblique. The *inferior rectus* turns the eye downward and inward; when the eye is turned directly downward, this is effected by the conjoint action of the inferior rectus and the superior oblique. The *internal*

FIG. 338.—Horizontal section of left eye. Arrows show direction of pull of the muscles. The axis of rotation of the external and internal recti would pass through the intersection of  $\alpha$  and  $\beta$  at right angles to the plane of the paper (Stewart).

*rectus* turns the eye inward; the *external rectus* turns it outward. The *superior oblique* rotates the eye outward on its anteroposterior axis, and corrects the inward deviation of the inferior rectus. The *inferior oblique* rotates the eyeball outward on its anteroposterior axis, and corrects the inward deviation of the superior rectus.

**Physiology of Vision.**—The eye has very aptly been compared to a photographic camera, the transparent structure, through which pass the rays of light, representing the lenses, and the retina representing the sensitive plate on which the image is received, while the pigmented choroid coat is the representative of the lampblack with which the photographer darkens the interior of the camera-box to prevent any reflected light striking the plate and interfering with the sharpness of the picture. In the camera, in order to bring to a focus upon the plate the rays of light coming from objects at different distances, the photographer uses a focusing screw, by which the lens may be moved nearer to or farther from the object he wishes to photograph; and in order that clear images may be obtained by the eye it is necessary to accomplish the same result, for when the eye is focussed for near objects, those at a distance are blurred, and *vice versa*. This fact may readily be demonstrated by looking through a piece of mosquito-netting at the windows of a house on the opposite side of a street. When

**FIG. 337.**—Principal focus of a lens. The parallel rays, *a, b, c, d*, are refracted by the lens so as to unite at the point *F* on the axis *P*; the ray *P* undergoes no refraction. *F* is the principal focus.

the threads of the net can be seen distinctly, the bars of the window will be indistinct, and when the bars of the window are clear and distinct, then the threads are blurred. In the optical apparatus of the eye there is no provision for altering the position of the lenses, but there is one which answers the same purpose, and which is called *accommodation*. In connection with every camera there is an arrangement of openings or diaphragms by which a greater or lesser amount of light may be admitted, according to circumstances. In the eye the iris serves a similar purpose. In many cameras it is necessary to have a number of such diaphragms, each having an opening of a different size, but some are provided with a single one, the size of whose opening can be altered; this is called an "iris diaphragm," and is a rude contrivance compared with the natural iris from which it derives its name, and which by means of its muscular fibers can alter in a moment the size of the pupil.

Rays of light coming from an object, in order to produce a distinct image of that object, must be brought to a focus upon the retina (Fig. 337). If the media through which the light from an

object passes to reach the retina were all of the same density as the air, and were also plane surfaces, an impression would be produced, but there would be no distinct image. Actually, before such rays do reach the retina they pass through certain media which, by reason of both density and shape, refract them and bring them to a focus, thus producing a sharp and distinct image of the object looked at. These media are the cornea covered with a layer of tears, aqueous humor, crystalline lens with its anterior and posterior capsule, and vitreous humor, seven in all. The amount of refraction is determined by the radius of curvature of the surface through which the rays pass, the refraction being greater as the radius becomes smaller, and by the difference between the refractive indices of the media, refraction increasing as the difference increases. The radii of curvature are as follows :

	When accommodated for	
	Far vision.	Near vision.
Cornea . . . . .	8 mm.	8 mm.
Anterior surface of lens . . . . .	10 "	6 "
Posterior " " " . . . . .	6 "	5.5 "

The refractive indices of the various media through which the light passes are as follows :

Tears . . . . .	1.3365
Cornea . . . . .	1.337
Aqueous humor . . . . .	1.3365
Vitreous " . . . . .	1.3365
Lens (mean for all layers) . . . . .	1.437

The refractive index of air is 1.000, and of water 1.335. From this table it will be seen that the tears, cornea, and aqueous humor have practically the same indices of refraction, and we may therefore regard the media through which light passes to reach the retina as three in number : 1, tears, cornea, and aqueous humor, with a refractive index of 1.33 ; 2, crystalline lens, with a refractive index of 1.43 ; and 3, vitreous humor, with a refractive index of 1.33.

The following table gives the distances between the various points mentioned therein :

	When accommodated for	
	Far vision.	Near vision.
Anterior surface of cornea and anterior surface of lens . .	3.6 mm.	3.2 mm.
" " " " posterior " "	7.2 "	7.2 "
" " lens " " " "	3.6 "	
Posterior " " retina " "	14.6 "	14.6 "

The anteroposterior diameter of an emmetropic eye along the axis is 21.8 mm.

The data here given are known as *optical constants*, and the figures may be regarded as averages, individual eyes differing, as would naturally be expected.

*Reduced Eye* (Fig. 338).—For purposes of calculation, an imaginary eye, the *reduced* or *schematic* eye, has been proposed,

FIG. 338.—The reduced eye: S, the single spherical refracting surface, 1.8 mm. behind the anterior surface of the cornea; N, the nodal point, 5 mm. behind S; F, the principal focus (on the retina), 20 mm. behind S. The cornea and lens are put in in dotted lines in the position which they occupy in the normal eye (Stewart).

whose refractive medium is a single one, representing, approximately enough for practical purposes, the natural eye. This eye has the following characteristics (Listing):

From anterior surface of cornea to the principal point . . . . .	2.3448 mm.
From nodal point to the posterior surface of lens . . . . .	0.4764 "
Posterior principal focus behind cornea . . . . .	22.8287 "
Anterior principal focus in front of cornea . . . . .	12.8326 "
Radius of curvature of single refracting surface . . . . .	5.1248 "
Index of refraction of single refractive medium . . . . .	1.33 "

The optical and visual axes may be regarded as identical, and as represented by a line which passes through the centers of curvature of the cornea and lens directly backward until it terminates

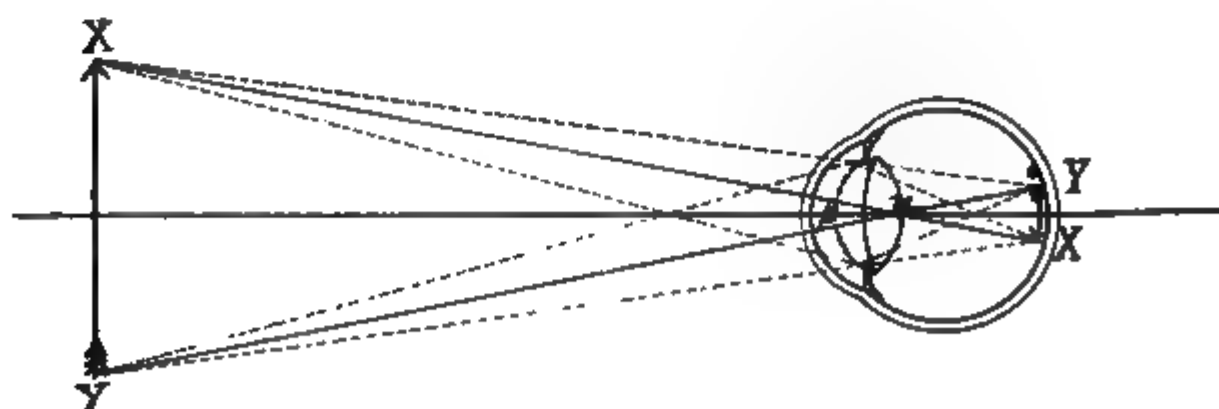


FIG. 339.—Diagram of the formation of a retinal image (after Foster).

in the fovea centralis. Rays of light falling upon the cornea are refracted and made convergent, and this effect is increased by the

lens and vitreous, so that when the rays reach the retina they are brought to a focus. This is shown in Fig. 339, where the arrow  $XY$  is projected upon the retina, forming the inverted image  $YX$ .

The angle  $xnY$  is the *visual* or *optical angle*, also called the *angle of vision*, and determines the size of the image upon the retina.

If an object subtends an angle less than 50 seconds, it cannot be seen, because the size of the image upon the retina would be less than  $3.65 \mu$ ; the distance between the centers of two adjacent cones being about  $4 \mu$ , each cone having a diameter of about  $3 \mu$ .

*Retinal Images are Inverted.*—By reference to Fig. 339 it will be seen that the retinal image is inverted; the question naturally arises, therefore, Why are not the objects which form these images seen in an inverted position? The answer to this question is that objects are “seen” by the brain, and not by the retina; that certain impressions are produced by the light upon the retina; and that these impressions are transmitted to the brain by the optic nerve, and are there interpreted in the form of what is

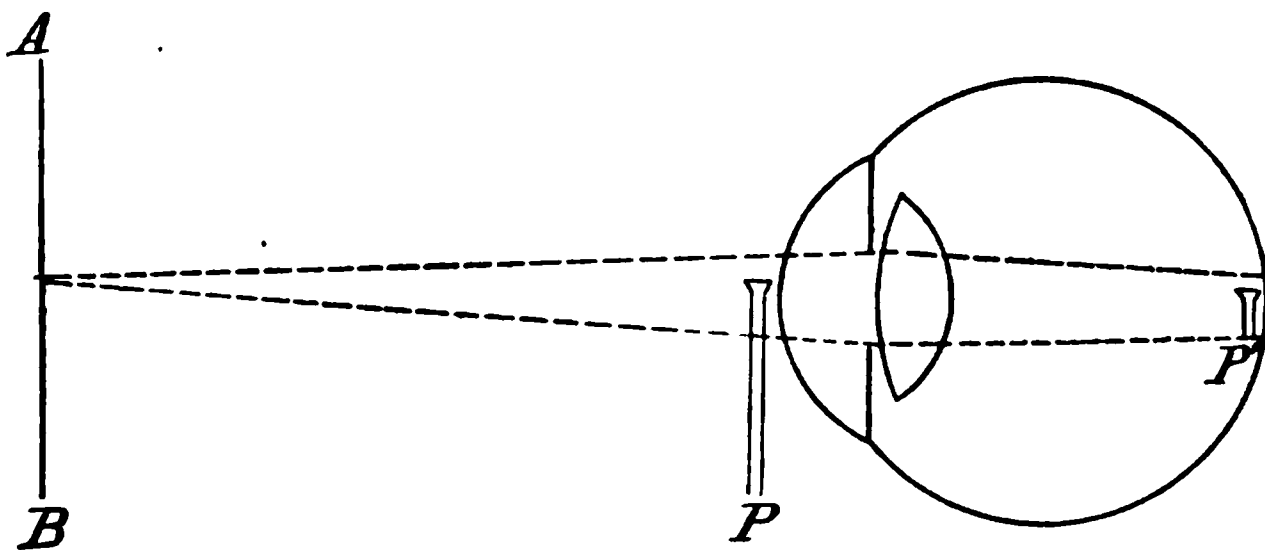


FIG. 340.—Diagram illustrating the projection of a shadow on the retina.

called “sight.” The brain has by long experience come to associate the top of an object with the image which the top of the object produces on the retina, so that although the upper end of an object—as the point of an arrow, for instance—makes its image below, and the lower end—or, in the supposed instance, the head of the arrow—forms its image above, the brain sees the arrow with its point up and the head down. Light which reaches the retina is always referred by the brain to an object situated on the opposite side. Thus light which reaches the right side of the retina comes from the left, and that which reaches its left side comes from the right.

It is a curious fact that when an upright object makes an upright image on the retina, the brain inverts the object, so that it is seen in an inverted position. This is illustrated in Fig. 340, for which and for the recital of the fact we are indebted to the *American Text-book of Physiology*. If a card with a small pinhole in it is placed in front of a source of light and about three or



four centimeters from the eye, and the head of a pin is held as close as possible to the cornea, the pinhole becomes a source of light, and the shadow of the pin, not the image—for the pin is too near the eye to form an image—falls on the retina. This shadow is an upright one, and yet the pinhead appears inverted, for the reason that the brain has become accustomed to interpret all impressions made upon the retina as corresponding to objects in the opposite portion of the field of vision. In the illustration, AB is the card with the pinhole, P the pin, and P' its upright shadow on the retina.

*Accommodation* (Figs. 341, 342).—The eye possesses the capability of adjusting itself to seeing objects at varying distances; this is *accommodation*. If the entire optical apparatus of the eye was rigid and immovable, it would be necessary, in order to obtain

FIG. 341.—Anterior quadrant of a horizontal section of the eyeball, cornea and lens cut in the middle of their vertical diameter: a, substantia propria of the cornea; b, Bowman's membrane; c, anterior corneal epithelium; d, Descemet's membrane; e, its epithelium; f, conjunctiva; g, sclera; h, iris; i, sphincter muscle of the iris; j, pectinate ligament of the iris with the adjacent fenestrated tissue; k, canal of Schlemm; l, longitudinal, m, circular fibers of the ciliary muscle; n, ciliary process; o, ciliary portion of the retina; p, canal of Petit, with the zonule of Zinn (Z) in front of it, the posterior leaflet of the hyaloid membrane (P) behind it; r, anterior, s, posterior, capsule of the lens; t, choroid; u, perichoroidal space; T, pigment epithelium of the iris; x, margin (equator) of the lens. (Landou).

a clear image of an object, either for the individual to approach or to recede from the object, or to cause the object to do the same with reference to him, for only parallel rays, namely, rays coming from objects at a distance of two to three meters or more, are brought to a focus in the normal eye unless some change is brought about in

the refractive media. If an object is within that distance, the rays of light coming from it are brought to a focus by altering the shape of the crystalline lens; this is *positive accommodation*.

As already stated, the optical apparatus of the eye is in a state of rest when it is looking at objects more than two to three meters

FIG. 342.—Diagrammatic representation of accommodation for near and far objects. On the right the condition during positive accommodation is shown, on the left the condition during rest (negative accommodation). On both sides one-half of the contour of the lens is drawn as a continuous line, the other half as a dotted line. The letters appearing twice—on both the right and left sides—have the same significance; those on the right side are primed. *A*, left, *B*, right half of the lens; *C*, cornea; *S*, sclera; *C.S.*, canal of Schlemm; *V.K.*, anterior chamber; *J*, iris; *P*, pupillary margin; *V*, anterior, *H*, posterior surface of the lens; *R*, equator of the lens; *F*, edge of the ciliary processes; *a* and *b*, interval between them. The line *Z-X* shows the thickness of the lens in the act of accommodation for a near object; *Z-Y*, the thickness of the lens when the eye is at rest. (Landois.)

distant, this is *negative accommodation*; thus to see the stars, although millions of kilometers distant, no effort is required; but if it is desired to see objects less than two or three meters away, there is a change in the refractive media until objects are brought to a point so close to the eye that no amount of effort will enable them to be seen. The point at which objects cease to be seen distinctly is called the *near point*, and it is, for a normal or *emmetropic* eye about 12 cm., although it is not the same in all persons.

The positive accommodation of the eye is brought about especially by the change in the shape of the crystalline lens; thus in looking at near objects the lens becomes more convex. This is accomplished in the following manner: The lens is a very elastic structure, enclosed in a capsule to which the zonule of Zinn is attached, and the tension of this structure is such as to pull upon the anterior portion of the capsule and flatten it, at the same time flattening the anterior surface of the contained lens. This is the condition when the eye is looking at distant objects or is in a state of *accommodative rest*. But when a near object is to be looked at, the radiating fibers of the ciliary muscle contract, and as its fixed point is at the junction of the cornea and sclerotic, this contraction draws the ciliary processes forward and relaxes the

zonule, thus removing the influence which tends to flatten the lens, and permits the latter, by its elasticity, to become more convex. The nervous supply for this act is furnished to the ciliary muscle by the motor oculi through the ciliary ganglion and nerves. At the same time that this muscular action is taking place the pupil becomes smaller and the eyes converge.

FIG. 343.—Reflected images of a candle-flame as seen in the pupil of an eye at rest and accommodated for near objects (Williams).

This is the usual explanation of accommodation, and may be demonstrated in the following manner: If in a dark room a candle-flame is held about 50 cm. distant from and at the side of the eye of a person who is looking at a distant object, an observer standing

FIG. 344.—Diagram explaining the change in the position of the image reflected from the anterior surface of the crystalline lens (Williams, after Donders).

at his other side will see reflected from the observed eye three images of the flame (Fig. 343)—(a) the brightest and most distinct being an erect image, which is formed by the anterior surface of the

cornea. Besides this image there is a second image (*b*), which is also erect, but which is less distinct and larger; this image is formed at the anterior surface of the lens. A third image (*c*) is also seen, which is inverted and also indistinct; this image is formed by the posterior surface of the lens, which, being concave forward, acts like a concave mirror and inverts the image. These are called *Purkinje-Sanson images*. If the person then looks as if at a near object, the second image becomes brighter and smaller, and at the same time approaches the first, while the first image undergoes no change, and the third a change so slight as not to be perceptible (Fig. 343). This proves that in accommodating the eye for near objects the principal change which takes place is an increase in the convexity of the anterior surface of the crystalline lens. There is also a slight increase in the convexity of the posterior surface, while the cornea remains unchanged. In Fig. 344 the course taken by the rays of light is delineated. The eye whose accommodation is under investigation is directed to *A*, while

*c*

FIG. 345.—Phakoscope of Helmholtz: at *BB'* are two prisms, by which the light of a candle is concentrated on the eye of the person experimented with; *A* is the aperture for the eye of the observer. The observer notices three double images reflected from the eye under examination when the eye is fixed upon a distant object; the position of the images having been noticed, the eye is then made to focus a near object, such as a reed pushed up; the images from the anterior surfaces of the lens will be observed to move toward each other, in consequence of the lens becoming more convex.

the candle-flame and the observer's eye are on opposite sides. The images of the candle-flame will appear along the line *II'*, on the dark background of the pupil. The image produced by reflection from the cornea is seen at the termination of the dotted line *a*; that from the posterior surface of the lens, at the termination of *c*; and that from the anterior surface of the lens when the eye is in a state of accommodative rest—i. e., looking at distant objects—

at the termination of  $b$ ; when focussed for near objects and the anterior surface of the lens moves forward, the image is seen at the termination of  $b'$ —i. e., nearer the corneal image; it is also smaller and brighter. The change in the convexity of the anterior

surface of the lens may also be shown by looking at the eye from the side, as in accommodation the iris may be seen to move forward, being pushed in that direction by the anterior surface of the lens, with which it is in contact.

*Phakoscope of Helmholtz* (Fig. 345).—This apparatus was devised by Helmholtz to demonstrate the changes which have just been described, and which were advanced by him to explain accommodation.

The eye of the person whose accommodation is to be studied is placed at  $C$ . For near vision the needle at  $D$  is to be looked at, and for distant vision some object in the same direction.

At  $B$  and  $B'$  there are two

FIG. 346.—Purkinje-Sanson images:  $A$ , in the absence of accommodation;  $B$ , during accommodation for a near object. The upper pair of circles enclose the images, as seen when the light falls on the eye through a double slit or a pair of prisms; the lower pair show the images seen when the slit is single and triangular in shape (Stewart).

prisms, in front of which a candle-flame is placed. The eye of the observer at  $A$  sees two sets of the three reflected images, each image being a square spot of light; those reflected from the anterior surface of the lens approach those reflected from the cornea, as already explained, and also approach each other (Fig. 346).

*Tscherning's Theory of Accommodation*.—This authority explains positive accommodation by supposing that by the contraction of the anterior part of both the radiating and circular fibers of the ciliary muscle the ciliary processes are drawn backward, and that this pulls the zonule of Zinn (suspensory ligament) backward and outward. This increases the tension of the ligament and the pressure upon the lens, the external or softer portion of which is caused to bulge out, this change being especially marked on its anterior surface. The contraction of the posterior portion of the ciliary muscle pulls forward the choroid, and thus makes tense, so to speak, the vitreous, preventing it from yielding when the lens is pressed against it by the anterior portion; thus the pressure of

the anterior portion of the muscle causes the increased convexity of the lens, and not its displacement backward.

*Schoen's Theory of Accommodation* (Fig. 347).—This writer explains the increased convexity of the lens by assuming that the contraction of the ciliary muscle produces the same effect on the lens as is produced upon a rubber ball when held in both hands and compressed by the fingers. The theories of Tscherning and Schoen presupposes a stretching of the zonule of Zinn, while that of Helmholtz is based on its relaxation. Recent observations of Hess seem to demonstrate that the change in this structure is one of relaxation rather than increased tension, so that at the present time the theory of Helmholtz may be accepted as the true explanation of accommodation.

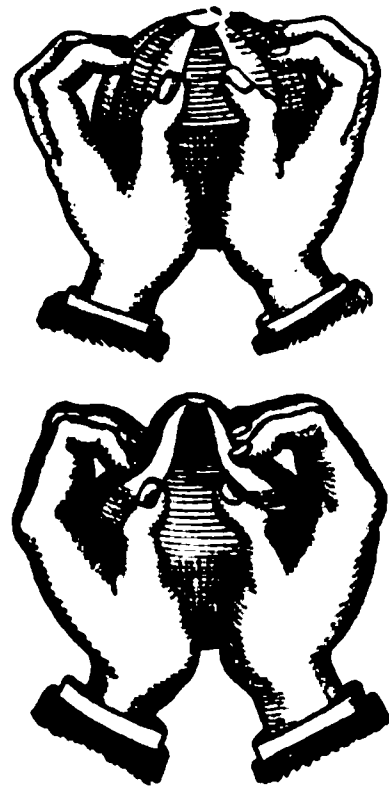


FIG. 347.—To illustrate Schoen's theory of accommodation.

*Range of Accommodation*.—The point nearest to the eye to which objects can be brought and be seen distinctly is the *near-point*; while the point farthest from the eye at which distinct vision exists is the *far-point*; the length of the intervening space is the *range of accommodation*.

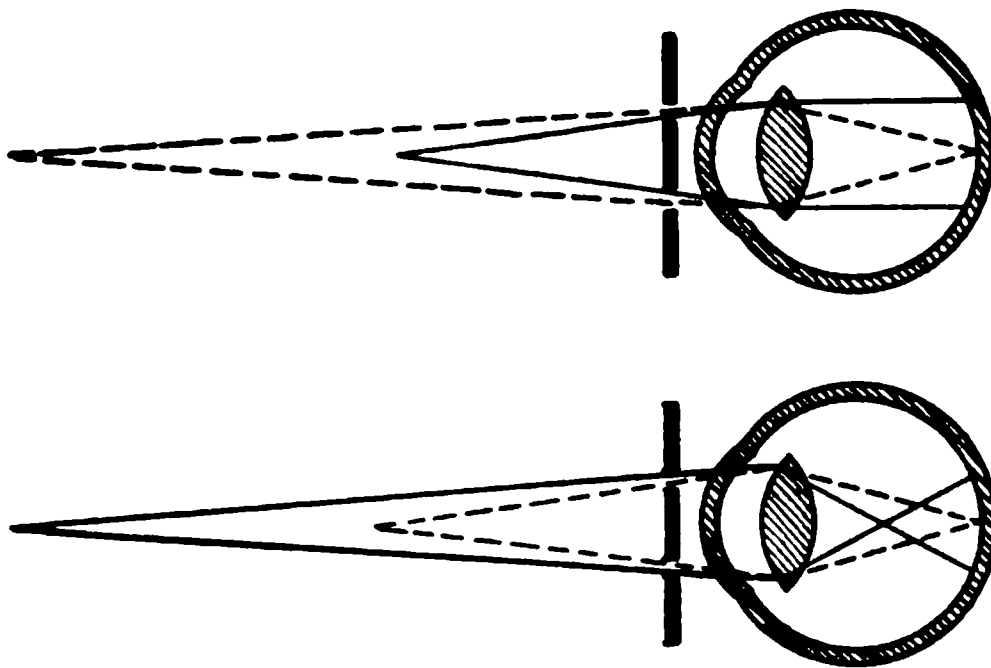


FIG. 348.—Scheiner's experiment. In the upper figure the eye is focussed for a point farther away than the needle; in the lower, for a nearer point. The continuous lines represent rays from the needle, the interrupted lines rays from the point in focus.

*Near-point*.—This is also called *punctum proximum*, and is expressed by p.p. It varies in different individuals, but for a normal adult eye is about 12 cm. Objects brought nearer to the eye than this cannot be seen with distinctness, for the refractive media cannot bring the image of such objects to a focus upon the retina. The near-point for any given eye may be determined by *Scheiner's*

*experiment* (Fig. 348). In a card two pinholes are made whose distance from each other must not exceed the diameter of the pupil, about 2 mm. Through these holes, with the card held close to the eye, a needle is looked at. It will appear single; if the needle is brought near to the eye, a point will be reached at which it appears double, or it may be blurred; this is the near-point for the eye in question.

*Far-point.*—This is also known as *punctum remotum*, or p. r. It is the farthest point at which objects can be seen distinctly by a normal eye, and is infinitely distant; so that the range of accommodation in the normal eye is from about 12 cm. to infinity. As a matter of fact, rays of light which reach the retina from any object not more than two meters distant from the eye are practically parallel, so that in looking at objects at any distance greater than this there is no change in the accommodative apparatus—i. e., the eye is in a state of accommodative rest; while as objects are brought nearer than two meters there is necessitated an increase in the convexity of the lens in order that they may be seen distinctly until the near-point is reached, within which their images become blurred by reason of the fact that the lens has reached the limit to which its convexity can be increased.

*Convergence of the Eyes during Accommodation.*—If, as an object is brought nearer to the eyes of an observer, his eyes are inspected by another, it will be seen that, as the accommodative apparatus is brought into action to focus the image on the retina, the eyes are at the same time turned inward—i. e., made to converge. When it is remembered that in order to produce distinct vision the image must be formed in the fovea centralis, it will be seen that as the object is brought nearer to the eyes each eye must be turned inward, otherwise the image would not fall upon the fovea.

*Contraction of the Pupil during Accommodation.*—When a distant object is observed, the pupil is relatively large; but when the eye is accommodated for near objects, the pupil becomes smaller. By this contraction of the iris the very divergent rays which come from the object, and which, by reason of their extreme divergence, would not be brought to a focus on the retina, are excluded, and thus a sharpness of the image is secured which would not be the case if the pupil was large enough to admit these rays.

*Defects in the Visual Apparatus.*—*Emmetropia* (Fig. 349, A).—The *emmetropic* or normal eye is one in which parallel rays are brought to a focus upon the retina when the eye is in a state of accommodative rest. In such an eye the near-point is about 12 cm. distant from the eye, the far-point at infinity, and from about two meters distant to an infinite distance objects can be distinctly seen without any change in the accommodative apparatus.

*Ametropia*.—Whenever the permanent condition of an eye is not as described above, it is one of ametropia. Of this condition, there are several varieties.

*Myopia* (Fig. 349, *B*).—A myopic eye is one that is abnormally elongated, and some authorities regard an increased convexity of the lens as constituting an essential part of this condition. The retina is so far from the lens that parallel rays are focussed in front of it, and, crossing, do not form distinct images on the retina, the images being blurred. To correct this, concave glasses are used, which cause these rays to diverge as they enter the eye, and by adjusting the concavity to the amount of myopia, parallel rays are brought to a focus on the retina as they are in the emmetropic eye without glasses. A myopic eye is commonly said to be a “near-sighted” one. The near-point in myopia may be 5 or 6 cm. from the eye, while the far-point is comparatively near the eye, never at an infinite distance, so that the range of accommodation is extremely limited.

*Hypermetropia* (Fig. 349, *C*).—In this condition the eye is shorter than normal, and the retina is too near the lens, so that parallel rays are brought to a focus behind the retina and indistinct vision is produced, as in the myopic eye. In the endeavor to overcome this defect the ciliary muscle is liable to overstrain in order to converge the rays to a focus upon the retina, and the constant effort is painful and injurious. The condition is corrected by the use of convex glasses. The near-point in the hypermetropic eye is farther than in the normal eye. The far-point does not exist, for objects would of necessity have to be removed to a greater distance than infinity, which is, of course, impossible, in order that the rays coming from them might be converging, and

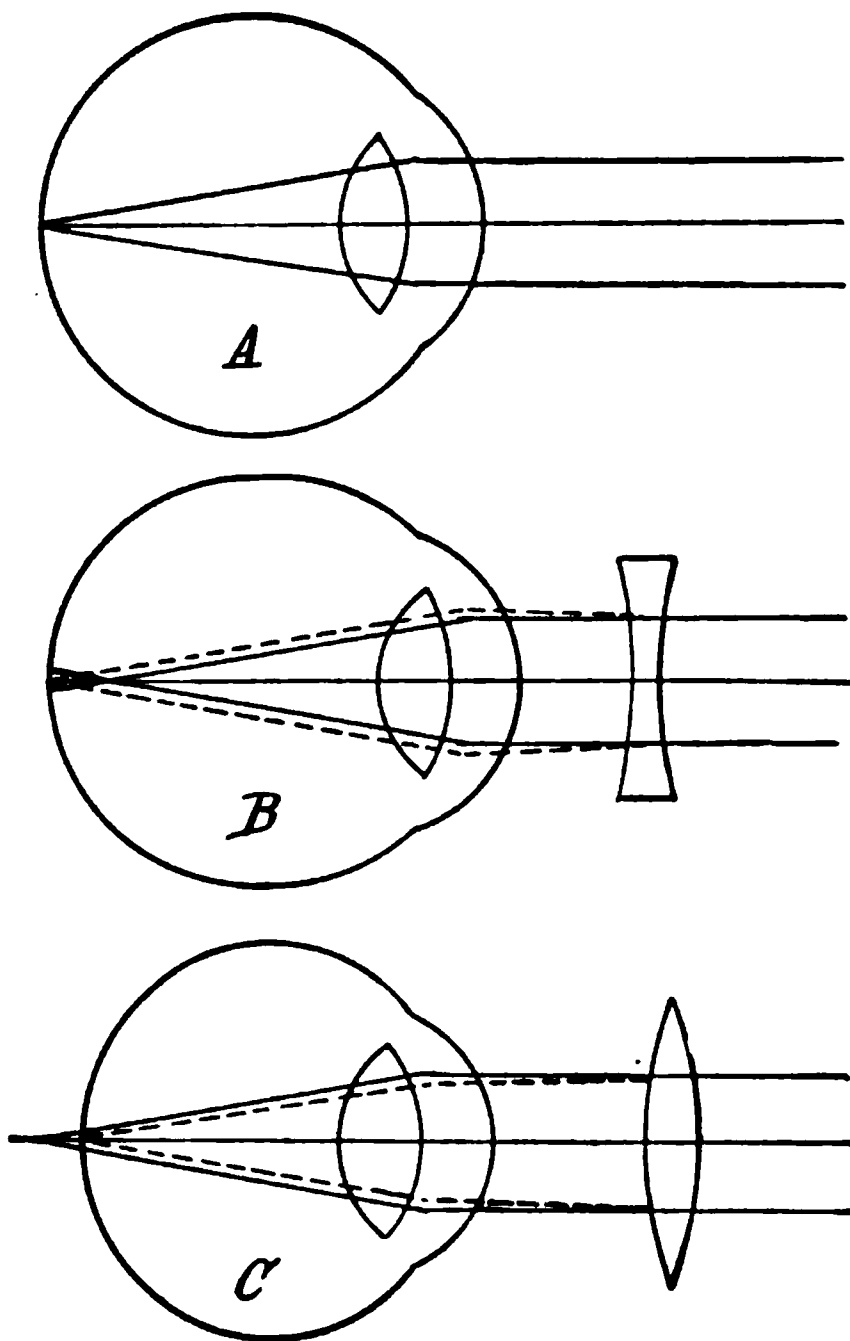


FIG. 349.—Diagram showing the difference between (*A*) emmetropic, (*B*) myopic, and (*C*) hypermetropic eyes.



thus these rays be brought to a focus upon the retina when the eye was in a state of accommodative rest.

*Presbyopia*, which is sometimes called "old sight," sometimes "long sight," is the condition of the eye present in elderly people. In this condition it is difficult to see near objects, although the vision for those at a distance is unaffected. It is usually attributed to a lessened elasticity of the lens, though the ciliary muscle is also less strong; some writers state that it depends on diminution of the convexity of the cornea. To aid in correcting it convex glasses are used.

Presbyopia may begin as early in life as the fifteenth year, although it commonly does not until about the fortieth year. The ability to see objects nearer by in advanced age, when previously spectacles were required, is explained by an increased refractive power which sometimes occurs under such conditions.

FIG. 350.—Lines for the detection of astigmatism.

*Astigmatism* (Fig. 350).—In this condition the cornea is usually at fault, its curvature being greater in one meridian than in another, and consequently the rays of light from an object are not all brought to the same focus, and the image, therefore, is not distinct. Astigmatism is *regular* when the curvature in any given meridian is regular in that meridian, although the meridian may differ in respect to curvature when compared with the one at right angles to it: the cornea is ellipsoidal and not spherical. Astigmatism is *irregular* when in any given meridian or meridians the curvature of the cornea is not an arc of a circle or an ellipse. It is irregular astigmatism which causes the stars to look as though rays projected from them. For the correction of regular astigmatism glasses are worn which are segments of a cylinder—that is, curved in but one direction—and are known as "cylindrical" glasses. Irregular astigmatism cannot be corrected by any glasses. The crystalline lens may also be at fault in astigmatism.

Regular astigmatism is detected by the observation of concentric rings or radiating lines, as in Fig. 350. In the former

some portions will be blacker and more distinct than others, while in the latter the lines will present the same differences.

*Spherical Aberration* (Fig. 351).—When rays of light are refracted, those which are incident near the edge of the lens are refracted more than those near the principal axis, and will, therefore, come to a focus in front of them, and produce an indistinctness of the image. This indefiniteness of focus is *spherical aberration*. To reduce this, a diaphragm is used in optical instruments, by which these marginal rays are excluded, or, as in large telescopic lenses, the same result is accomplished by diminishing the curvature of the lens at its margin. This

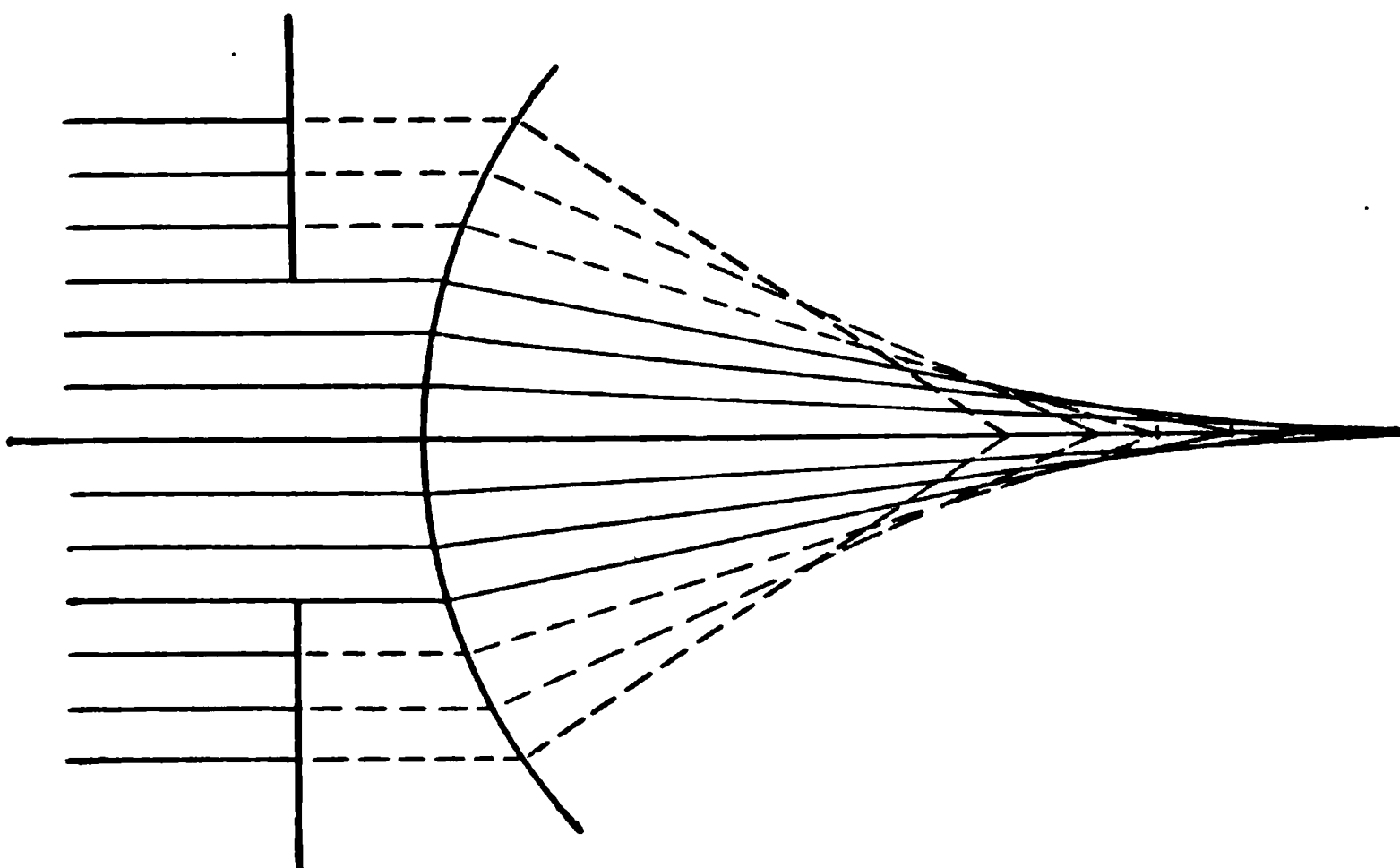


FIG. 351.—Diagram showing the effect of a diaphragm in reducing the amount of spherical aberration.

defect exists in the eye, and is lessened by the iris, which serves as a diaphragm to cut off the marginal rays, and also by the diminished refractive power of the marginal portions of the lens as compared with its center.

Spherical aberration is more marked with divergent than with parallel rays, and as rays are more divergent the nearer the object from which they come is to the eye, this is corrected by the greater contraction of the iris—*i. e.*, the greater diminution of the pupil—which results in cutting off more of the marginal incident rays. In the human eye spherical aberration is not an important defect.

*Chromatic Aberration*.—White light being a mixture of rays of different colors, and these differing in refrangibility, the red being the least and the violet the most refrangible, when white light passes through a lens it is broken up into its component rays

—i. e., undergoes *dispersion*—and the most refrangible or violet rays will be brought to a focus nearer the lens (Fig. 352) than the least refrangible or red rays, and between will be the various intermediate colors. When these rays fall upon a screen there will be produced a series of circles of the different colors. In Fig. 352 it will be seen that if the screen was placed at  $x$ , the outer color would be red, and the inner violet; while if it was

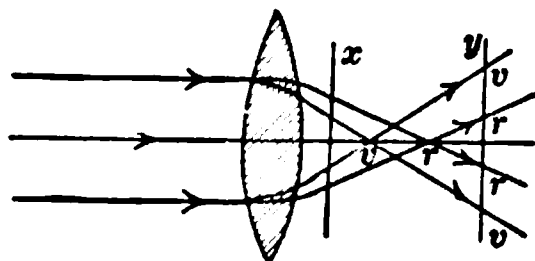


FIG. 352.—Chromatic aberration (Carhart and Chute).

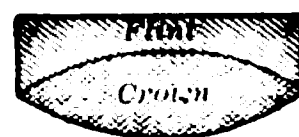


FIG. 353.—Achromatic combination of lenses (Carhart and Chute).

placed at  $y$ , the colors would be reversed. This defect in lenses is *chromatic aberration*, and is overcome by combining a biconvex lens of crown glass with a planoconcave lens of flint glass (Fig. 353). Inasmuch as images formed by rays which have passed through such a combination are not fringed with color, the combination is *achromatic*.

It is a rather curious fact that the eye was at one time supposed to be free from this defect, and its absence was explained by the fact that the different media through which light passes to reach the retina differ so in their refracting power as to overcome dispersion; and it is said that it was this which led to the combination just described of the crown and flint glass to make the achromatic lens. The media of the eye, however, do not form an achromatic combination, but the violet rays are actually

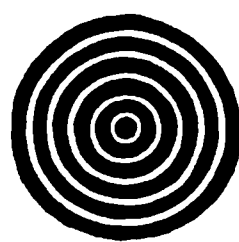


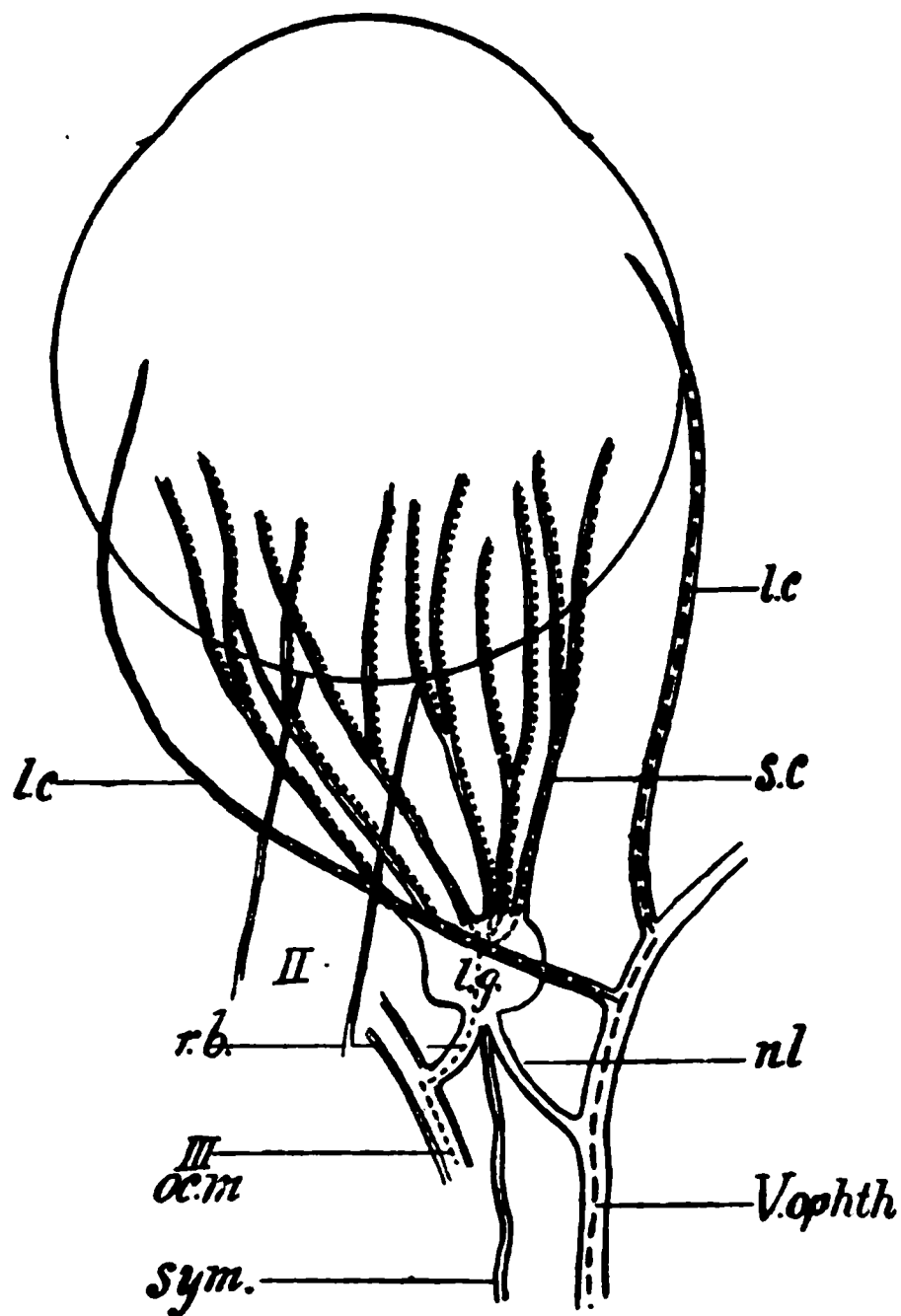
FIG. 354.—To show dispersion in the eye, view the figure from a distance too small for accommodation. Approach the eye toward it: the white rings appear bluish, owing to circles of dispersion falling on them. A little closer, and the black rings become white or yellowish-white, being covered by circles of dispersion and diffusion.

brought to a focus about 0.5 mm. in front of the red. Under ordinary circumstances this produces no confusion; and yet that this defect is inherent in the human eye may be readily demonstrated. If Fig. 354 is brought very close to the eyes—so close that the two crystalline lenses cannot accommodate for it—the white rings become bluish on account of circles of dispersion falling on them, and if brought a little closer, the black rings become of a yellowish-white color. This dispersion also explains *irradiation*.

**The Iris.**—The iris possesses two sets of muscular fibers, the circular and the radiating. Some authorities question the existence of the radiating muscular fibers, regarding them as elastic rather than contractile, and explain dilatation of the pupil by supposing that the circular fibers cease to contract, and that by the elasticity of the radiating fibers the pupillary margin of the iris is drawn outward. It seems to us, however, that the existence of contractile radiating fibers has been sufficiently demonstrated. By the enlargement or diminution of the size of the pupil the amount of light which is permitted to pass into the eye is regulated. The pigment in the iris makes it opaque, and thus only such light as enters the pupil can reach the retina. We have seen that it is the iris which, excluding the marginal rays, minimizes spherical aberration; and that contraction of the pupil takes place during accommodation. The three functions of the iris may, therefore, be regarded as (1) to regulate the amount of light which falls upon the retina; (2) to minimize spherical aberration; and (3) to assist the accommodative apparatus in the production of distinct vision for near objects.

In the changes which take place in the iris, two sets of nerves are involved

(Fig. 355): (1) Those of the third nerve or oculomotorius; and (2) those of sympathetic origin. The third nerve supplies the circular fibers, and consequently section of this nerve paralyzes these fibers, and dilatation of the pupil occurs. When the third nerve is stimulated, the circular fibers contract, causing a diminution in the size of the pupil. The sympathetic supplies the radiating fibers, and



Course of constrictor nerve-fibers .....  
Course of dilator nerve-fibers .....

FIG. 355.—Diagrammatic representation of the nerves governing the pupil: *II*, optic nerve; *l.g.*, ciliary ganglion; *r.b.*, its short root from *III*, motor oculi nerve; *sym.*, its sympathetic root; *r.l.*, its long root from *V*, ophthalmic branch of ophthalmic division of fifth nerve; *s.c.*, short ciliary nerves; *l.c.*, long ciliary nerves (Foster).

its section paralyzes these fibers, causing contraction of the pupil, while its stimulation produces dilatation.

*Mydriatics* are drugs which cause the pupil to dilate ; *atropin* is a well-known mydriatic. *Cocain*, *daturin*, and *hyoscyamin* likewise produce dilatation of the pupil, and are therefore mydriatics.

*Myotics* are drugs which produce contraction of the pupil. Prominent in the list of myotics are *eserin*, *pilocarpin*, and *morphin*. The mydriatics probably act by *paralyzing* the oculomotorius and stimulating the sympathetic. When large doses are used, the circular fibers may be paralyzed directly. Myotics paralyze the sympathetic and stimulate the oculomotorius.

In addition to producing dilatation of the pupil, the mydriatics paralyze the accommodation, so that as long as their effect lasts it is impossible to focus the eye for near objects. Myotics, besides contracting the pupil, cause a contraction of the ciliary muscle, and thus the lens is adjusted for near objects.

When light falls upon the retina this portion of the eye is stimulated, and the impression is carried by the optic nerve to the brain, and there motor impulses are generated which are transmitted through the third nerve to the sphincter of the iris, causing it to contract ; this is, therefore, a reflex act. When one goes from the dark into the light, the pupil contracts, but this contraction lasts only a short time, and is followed by dilatation, and in a few minutes the size of the pupil is about the same as at first. If, on the other hand, one goes from the light into the dark, there is at first a dilatation of the pupil, then a contraction, and in about twenty minutes the pupil is as it was before the dilatation. These observations demonstrate that there are other influences than the incidence of light upon the retina to produce the changes in the pupil.

**The Retina.**—As odors excite the olfactory apparatus and savors excite the gustatory, so does light excite the retina. As neither odors nor savors reach the brain, where smell and taste are produced, but only the nerve-impulses which they excite and which the olfactory and gustatory nerves transmit, so when the light-waves fall upon the retina they go no farther ; but the nerve-impulses which they there excite are carried to the brain by the optic nerve and produce the sensation called "light." Thus it is that a blow upon the eye or an injury to the optic nerve produces in the brain the impression of a flash of light, although the room in which the blow or injury was received may be absolutely dark.

That the optic nerve is itself insensitive to light is shown by the fact that at the point where it enters the eye, forming the optic disk, is the "blind spot," at which there is an entire absence of sight. This fact may be demonstrated in the following simple

way: Look with the right eye at the round black spot here printed,



closing the left eye, and holding the book six inches from it. The spot and the cross can both be seen. Now carry the book away from the face farther and farther, still looking at the spot. A point will be reached where the cross will at once disappear, and when this occurs the light from the cross falls upon the optic disk. If the book is carried still farther, the cross will again come in sight.

There is no doubt that the portion of the retina which reacts to the stimulus of light is the layer of rods and cones, and of this layer the cones are especially sensitive. This is shown by the fact that the macula lutea (yellow spot) is the portion of the retina which is the most sensitive, and here there are no nerve-fibers, but rods and cones, and in the fovea centralis, which is the most sensitive portion of the macula, only cones are found.

*Purkinje's Figures.*—It may also be shown by the following experiments: 1. If in a dark room a small candle-flame is moved to and fro, close to and at the side of the eye, while the latter is directed toward the dark, an outline of the blood-vessels of the retina will be seen. 2. Or, if after the eyes have been closed for

FIG. 356.—Method of rendering the retinal blood-vessels visible by concentrating a beam of light on the sclerotic. From the brightly illuminated point of the sclerotic,  $a$ , rays issue, and a shadow of a vessel,  $v$ , is cast at  $a'$ . It is referred to an external point,  $a''$ , in the direction of the straight line joining  $a'$  with the nodal point. When the light is shifted so as to be focussed at  $b$ , the shadow cast at  $b'$  is referred to  $b''$ —i. e., it appears to move in the same direction as the illuminated point of the sclerotic (Stewart).

some time, as upon awaking from sleep, the eyes are directed for an instant to a white ceiling, an outline of the retinal blood-vessels

may be seen. If the eye is quickly closed and again opened, this outline may be again seen, and this may be repeated several times. 3. A third method of demonstrating the retinal vessels is by concentrating a strong light on the sclerotic, at a part as distant as possible from the cornea, by means of a lens, as is shown in Fig. 356. 4. If a card is perforated with a pin, and then held close to the cornea, and through the pinhole light from a lamp or other source of illumination is allowed to fall on the retina, when the card is moved rapidly up and down or from side to side, but not so much as to prevent the light from entering the pupil,

FIG. 357.—Figure to illustrate the principle of the ophthalmoscope. Rays of light from a point,  $P$ , are reflected by a glass plate,  $M$  (several plates together in Helmholtz's original form), into the observed eye  $E'$ . Their focus would fall, as shown in the figure, at  $P'$ , a little behind the retina of  $E'$ . The portion of the retina  $AB$  is therefore illuminated by diffusion circles; and the rays from a point of it,  $F$  will, if  $E'$  is emmetropic and unaccommodated, issue parallel from  $E'$  and be brought to a focus at  $F'$  on the retina of the (emmetropic and unaccommodated) observing eye  $E$ .

a shadow of the blood-vessels of the retina will be seen. These shadows of the retinal blood-vessels are *Purkinje's figures*.

The retinal blood-vessels do not extend beyond the inner nuclear layer, and the fact that these vessels cast a shadow when light is admitted to the eye, as in the experiments just referred to, demonstrates that the sensitive portion of the retina lies behind the blood-vessels, and the distance behind can be calculated by measuring the amount of change of position the shadows undergo when the light is moved about. This has been done, and the distance has been ascertained to be about 0.2 mm. to 0.3 mm. behind the vessels, which corresponds to the layer of rods and cones.

*Circulation of Blood in the Retina.*—Not only is it possible to see the shadow of the retinal blood-vessels, but the movement of

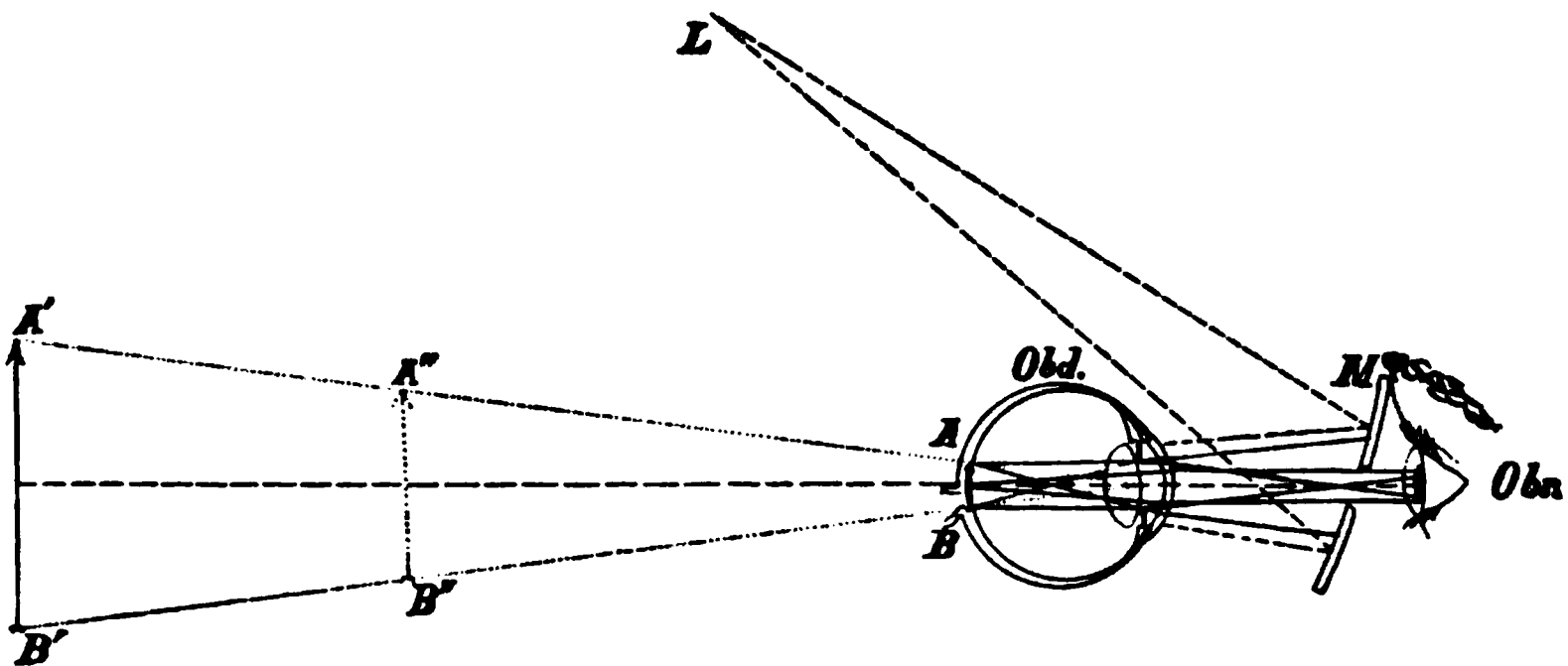


FIG. 358.—Diagram of the direct method with the formation of an upright image. Rays from the source of light  $L$  are received upon the concave mirror  $M$ , and converged upon the observed eye  $Obd.$ , within which they cross and illuminate an area of its fundus. From an area  $AB$  thus lighted, rays pass out of the pupil (parallel if it be emmetropic, as here represented) through the sight-hole of the mirror, and, entering the observer's eye,  $Obr.$ , are focussed upon the retina. An image is there formed as though the object seen was at a great distance, and the perceptive centers project it into space as though the object was at some arbitrary distance (*e. g.*, 25 cm.). By the laws of magnification by a simple lens the image is embraced between the lines passing from the optical center of the magnifying-lens (the refracting system of the observed eye), through the extremities of the object, and has the size  $A'B'$ ,  $A''B''$ , etc., according to the distance of projection (Randall).

the corpuscles within these vessels can also be seen if the eye is directed toward the sky. They appear as bright little bodies,

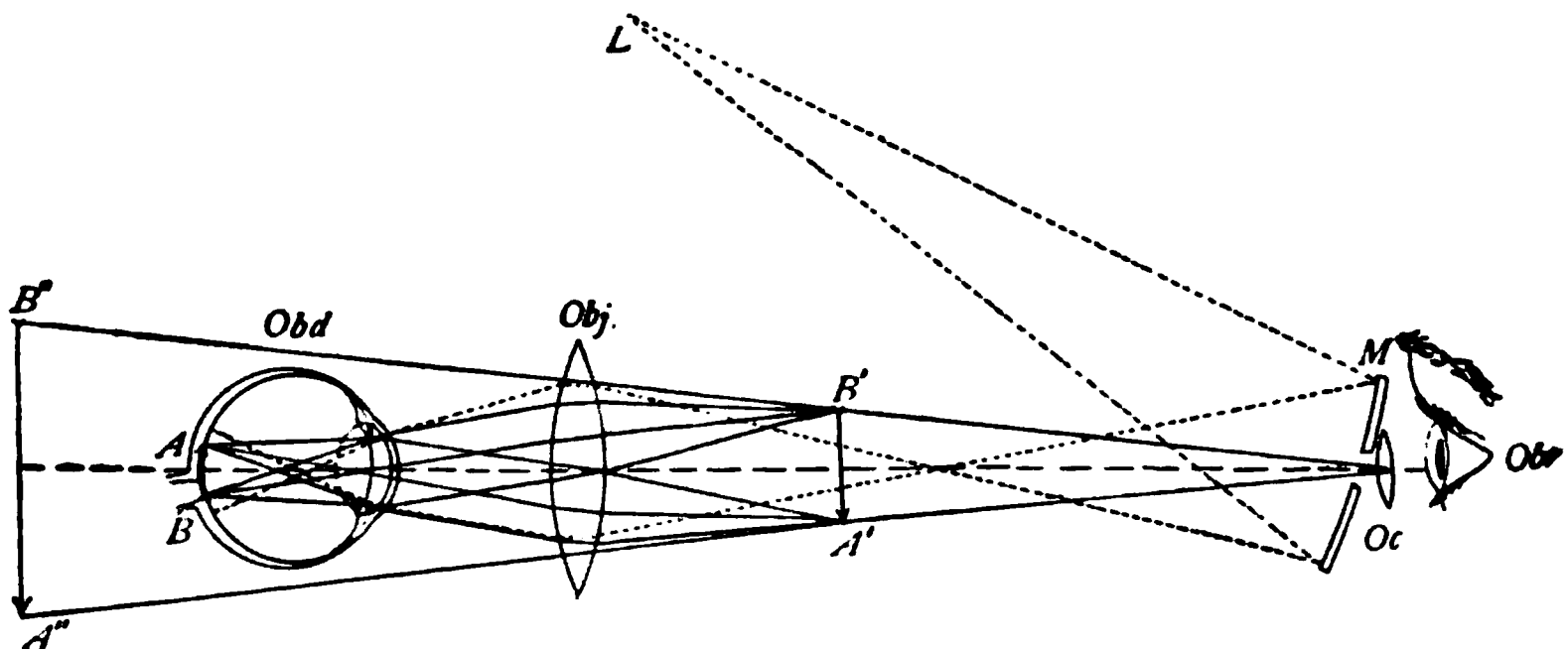


FIG. 359.—Diagram of the indirect method, giving an inverted image: rays from the source of light  $L$ , converged toward the observed eye  $Obd$  by the concave mirror  $M$ , are intercepted by the lens  $Obj.$ , and after coming to a focus diverge again and light up the fundus. From a part of the illuminated fundus  $AB$  rays pass out of the pupil to be again intercepted by the lens  $O$ , and form an inverted real image at its anterior focus  $A'B'$ . This real image is viewed by the observer's eye behind the sight-hole of the mirror with the aid of a magnifying-lens  $Oc$ , and is seen enlarged, as at  $A''B''$  (Randall).

moving rapidly and uniformly through the field. If cobalt glass is held in front of the eyes, the corpuscles are more readily dis-



cernible. The velocity of the flow of blood in the capillaries of the retina is from 0.5 mm. to 0.9 mm. per second.

*Intra-ocular Images.*—In addition to the blood-vessels and blood-corpuscles, other objects within the eye may throw shadows upon the retina; indeed, any opacity in the media of the eye through which the rays of light pass would do this, as, for instance, the *muscæ volitantes*. These are little bodies floating in the vitreous, which are supposed to be the remains of cells or fibers which exist during fetal life, and which have not become converted into the vitreous humor, as have most of the cells and fibers. They assume various shapes in different individuals, but the shape is invariable in the same person. They may appear as a string of beads, or in the form of streaks or granules.

*The Ophthalmoscope.*—This is an instrument by means of which one person can examine the eye of another and obtain a view of the retina. Inasmuch as some of the rays of light which enter the eye and fall upon the retina are reflected from the surface and are brought to a focus again at the source of illumination, it is manifest that without some special device it would be impossible to see the image which these reflected rays make, for to have the eye of the observer in the path of these reflected rays would cut off the light which caused them. To overcome this obstacle, Helmholtz devised the ophthalmoscope, which consisted of several plates of glass, one upon another (Fig. 357), that reflect rays of light from a lamp or other source of illumination into an eye to be examined; these rays illuminate the retina, and those that are reflected issue from the observed eye and are brought to a focus on the retina of the observer. The observed eye and that of the observer are considered to be emmetropic and in a condition of negative accommodation or accommodative rest. A reference to Fig. 357 will render this explanation clearer. At the present time glass plates are not used, but in their place a concave mirror, with an opening in it, through which the observer can look. There are two methods of using the ophthalmoscope: the direct (Fig. 358) and the indirect (Fig. 359). These will be readily understood after an examination of the illustrations and their respective legends.

It is customary, though not absolutely necessary, before making an ophthalmoscopic examination to drop into the eye a solution of atropin of a strength of two grains to the ounce. This paralyzes the accommodation and dilates the pupil. The examination is conducted in a dark room.

The illuminated retina produces a red glare, the *reflex*, which, as the observed turns his eye slightly inward, becomes lighter in color, because of the white surface, the *optic disc*, from which the light is reflected when the eye is in this position; in its center is the *porus opticus*, with the *arteria centralis retinae*, and radiating from this are its branches; *veins* also are seen. The *macula lutea* and the *fovea centralis* may likewise be discerned.

The ophthalmoscope is used to detect changes in the retina, as in Bright's disease of the kidneys, and also for testing errors of refraction, as in myopia and hypermetropia. For this latter purpose *skiascopy* also is employed, which is defined as "a method of determining the refraction of the eye by examining the movements of light and shadow across the pupil when the retina is illuminated by light thrown into the eye from a moving mirror."

**Light.**—The word "light" is used in two senses: 1. With reference to the sensation produced in the brain; and 2. With reference to the cause of that sensation.

Light, the cause, is defined as "the form of radiant energy that acts on the retina of the eye, and renders visible the objects from which it comes; the illumination or radiance that is apprehended by the sense of vision" (*Standard Dictionary*). It is "a periodic disturbance in a very subtle and highly elastic medium which is supposed to exist everywhere in space, even pervading the intermolecular spaces in matter. This medium is known as the *ether*, and vibrating disturbances in it give rise to all the phenomena of radiant energy. These disturbances are propagated through it as waves, not of compression and rarefaction, but more like those of the rope, the direction of vibration being transverse to that of propagation" (Carhart and Chute). The reference to "the rope" is to an experiment of laying a soft-cotton rope, about 5 feet long, on a floor, and then, holding one end of the rope in the hand, setting up vibrations in it by a quick up-and-down movement of the hand.

When these waves in the ether reach the retina they produce the sensation of sight, and, as has been stated, the portion of the retina which is sensitive to light is the layer of rods and cones. Just how this is accomplished is not known. Various theories have been advanced to explain it: (1) That the waves of light become waves of heat and thus act as *thermic* stimuli to the rods and cones; (2) that the waves of light become waves of electricity, and that the stimuli are *electric*; and (3) that these waves produce certain chemical changes, so that the stimuli are *chemical*. The first and second theories may be passed by with a mere mention, and, although the third is far from proved, yet there are facts which make the theory worthy of attention and continued investigation, as a result of which the true explanation may be forthcoming.

In the outer portions of the rods of the retina is a pigment, *rhodopsin* or *visual purple*, which, when the retina is exposed to light, becomes red, then orange, then yellow, and finally fades away. When the eye is exposed to light, the pigmented epithelium of the retina sends pigmented processes between the rods and cones, and this pigment, fuscine, forms visual purple again, and this reappears in the rods. If the pigmentary layer is separated from the other layers of the retina, the formation of the rhodopsin, after it has been bleached by light, does not occur. If an eye, after having been protected from the light for a con-

siderable time, is then exposed so as to receive the image of a window upon the retina for a time varying from several seconds to several minutes, according to the intensity of the light, and the retina is then removed and inspected in a red light, the image of the window will be seen in it. Such an image is an *optogram*, and is due to the action of the light on the visual purple, bleaching it in some places, and but little affecting it in others. This image may be preserved, or, as photographers say, "fixed," by putting the retina in a 4 per cent. solution of alum.

While it might at first seem as if these changes in the rhodopsin explained what actually took place in the eye when the waves of the luminiferous ether reached the retina and produced the sensa-

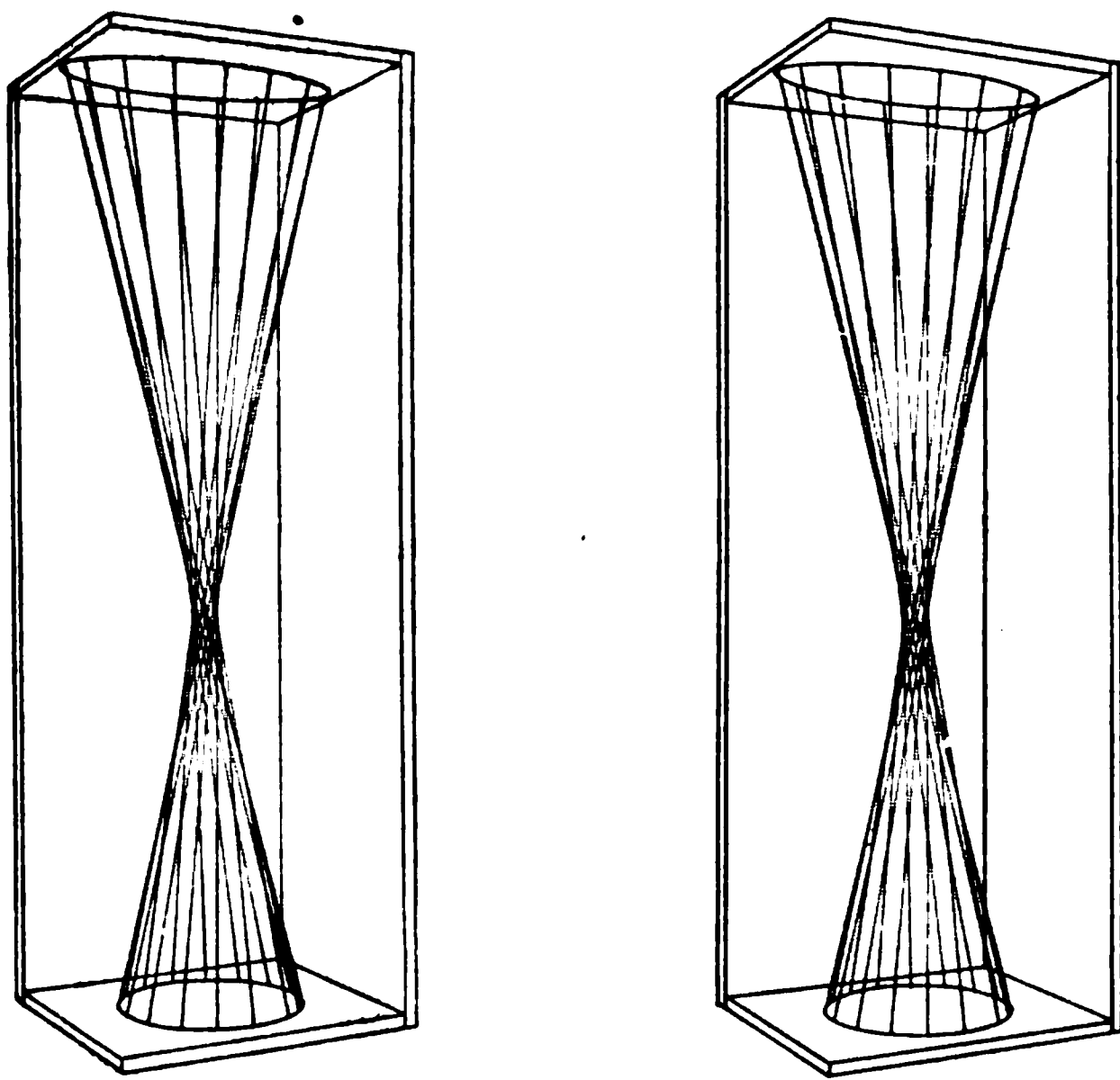


FIG. 360.—Model to illustrate astigmatism.

tion of light, still the absence of this coloring-matter from the cones, which exist without the rods in the fovea centralis, where sight is most acute, would alone be sufficient proof that the visual purple is not essential to vision. Some animals possessing sight have no visual purple even in the rods.

Engelmann has described a shortening and a thickening of the cones of frogs and fishes under the stimulation of light, and a lengthening in the absence of light, but as to the connection between these changes in the cones and sight, nothing is known.

The eye is able not only to see objects, but to take cognizance of certain facts in connection with them, such as their form, size, distance, and color.

**Form.**—Plane surfaces can be seen with either eye alone, but solid bodies require the combined use of both eyes, or *binocular vision*, in order that their solidity may be appreciated. If a solid object is looked at with the left eye, while the right eye is closed, and then with the right eye while the left is closed, it will be observed that with the left eye more of the left side of the object is seen than with the right eye, and with the right eye more of the right side of the object than with the left eye. The two images produce the effect in the brain of a single solid body. This principle is made use of in the *stereoscope* (Fig. 361). The picture which is seen with this instrument is double, each having been taken with a separate lens, so that when their images are thrown on the retina the effect is as if both eyes were looking at the scene represented in the photographs.

**Identical Points.**—It would seem *a priori* that each retinal image would produce its own effect upon the brain, and that, instead of seeing a single object, it would appear double. The theory of identical or *corresponding points* has been advanced to explain what actually takes place. If one retina is in imagination placed upon the other, the foveæ centrales superimposed the one upon the other, all the other points of the retinæ similarly superimposed are identical or corresponding points, and images formed upon such points will in the brain produce the effect of single vision. When the images of an object are not formed upon identical points, double vision or *diplopia* results. If, therefore, while looking at an object we press with the finger upon the outer side of one eye so as to turn it a little inward, we see the object double.

**Size.**—The size of objects is determined by two factors: The size of the visual angle which they subtend, and their distance from the observer. Helmholtz has demonstrated that an object which subtends a visual angle of less than  $50''$  cannot be seen by the unaided emmetropic eye. This corresponds to an image on the retina of  $3.65 \mu$ . The diameter of each cone in the macula lutea is about  $3 \mu$ . Kölliker gives it as  $4 \mu$  to  $5 \mu$ . In other words, if an object does not make an image on the retina large

FIG. 361.—Brewster's stereoscope:  $p$  and  $r$  are prisms, with their refracting angles turned toward each other. The prisms refract the rays coming from the points  $c$ ,  $r$  of the pictures  $ab$  and  $a\beta$ , so that they appear to come from a single point,  $q$ . Similarly the points  $a$  and  $a$  appear to be situated at  $f$ , and the points  $b$  and  $\beta$  at  $\phi$ .

enough to stimulate a cone, it does not come within the range of vision.

**Distance.**—It is impossible to judge of the distance of objects except by experience ; thus a child reaches for everything it sees, irrespective of the distance from it the objects may be ; and persons who, having been blind from birth, are in maturer years endowed with sight—by operation, for instance—bear testimony that everything seems to be immediately in front of them. If, however, the size of an object is known, then the size of its image on the retina determines our estimate of its distance. Conversely, if we know the distance of an object, then the image which that object produces on the retina is the determining factor in our judgment of its actual size. If, therefore, our judgment of the distance of an object from us is erroneous, so will be our judgment of its size, and *vice versa*. If, for instance, a ship is seen through a fog, we suppose that, being indistinctly seen, it is at a considerable distance from us, although, as a matter of fact, it may be quite near, and making an image of considerable size upon the retina, we judge the ship to be larger than it actually is. It is a well-known fact that the moon seems larger to an observer when near the horizon than when near the zenith, although, as a matter of fact, it is nearer by about 4000 miles, half the diameter of the earth, when in the zenith, and should therefore *a priori* seem larger, but when it is near the horizon we have terrestrial objects to compare it with, while when in the zenith there is nothing with which to compare it.

The correctness of this explanation has been questioned by a critic, who says : “ The moon looks large when rising on Salisbury Plain, on which there is no conspicuous terrestrial object with which it can be compared, and looks small at its zenith when close to the vane of the spire of Salisbury Cathedral, the size and distance of which are well known. It is probably an affair of refraction.”

As this illusion is almost universal, and one of great interest, the writer deemed it worth while to obtain the views of several well-known physicists. Among those written to was Prof. Spice, of Cooper Union, New York. In commenting on the criticism above quoted, he says :—“ Though it is true that there is no ‘ conspicuous ’ object in sight, still there is at least the Plain—and this would give one an idea of distance. With reference to the proximity to the vane on the cathedral spire, I would suggest that *unless* an observer were *on* the spire the vane itself would (of necessity) look *small*, and therefore would *not* tend to make the moon look large. As to the idea of refraction *increasing* the apparent size : The refraction *at* the horizon is about  $34' +$  ; the apparent diameter of the moon is about  $31' +$  ; so if the moon

were *just below* the horizon it would appear just *on* the horizon. Further, if the moon were just *on* the horizon the *lower* part of the moon would be raised (by refraction) *more* than the *upper* part, because refraction diminishes *rapidly* after leaving the horizon, so the *vertical* (apparent) diameter of the moon would be *less*, but the horizontal diameter would not change—*i. e.*, the area (size) of the moon at the horizon would be *smaller* by refraction.

“As to the apparent greater size of the moon when near the horizon, I believe that—as stated in most astronomy books, say Charles Young’s or Todd’s *New Astronomy*—it is due to the fact that in looking at the moon in that position we see many well-known objects as well: houses, trees, etc.; and as we have a rough idea of the size of *these* objects and also know they are nearer us than the moon is, we get the idea of largeness. In the zenith we have no objects for comparison, and as angular magnitude *alone* conveys no meaning, we have nothing to guide (or misguide) our judgment. Of course, when in the zenith, the moon’s angular size is very slightly *greater*, as we are nearly 4000 miles nearer—*i. e.*, by the radius of the earth. I may remark that the common notions as to the moon’s size are curious: one person may say it looks as ‘big as a dinner-plate,’ and another, ‘as big as a half-dollar,’ but in no case which I have examined have these thoughtful people made *any* mention of how *far* from *them* the dinner-plate was supposed to be at the time.”

Prof. C. A. Young, the well-known astronomer, of Princeton University, was written to for his explanation of the phenomenon; his answer is as follows:—“As to the phenomenon to which you refer, the apparent enlargement of celestial objects near the horizon, I am satisfied with the generally received explanation that it is due to the fact that while the *angular* diameter of the object remains practically the same as at the zenith (really a little less), the object is instinctively referred to a greater distance because of the number of intervening objects by which we judge of distance.

“If the sun or moon be looked at through a smoked glass, which leaves the disc visible while hiding the horizon and intervening objects, the sun or moon immediately shrinks to the same apparent diameter as if higher up. At least it is so with me, and with most persons whom I have seen try the experiment. Looking through a tube like a piece of gas-pipe 12 inches long is just as effectual; what is necessary is to cut out all objects and the horizon line while still leaving the moon (or sun) visible. But *some* persons say they do not get the effect. In their case I judge that the *habitual* sense of the horizon as distant comes in to maintain the illusion, even though they cannot actually see it, but I am aware that some physiologic psychologists decline to accept the explanation”



The New International Encyclopædia regards the apparent enlargement as due to an illusion of distance. The distance between the observing eye and the horizon seems to be longer than the distance between the eye and the zenith, owing to the haziness of the air, the number of intervening objects, etc. The retinal image being practically the same in both instances, the object which the mind refers to a greater distance appears to be larger.

Prof. Pickering, of Harvard College Observatory, in his book, *The Moon*, in treating of this subject, says :

“The true angular size of the moon is about half a degree; it can, therefore, always be concealed behind a lead-pencil held at arm's length. The sun and moon when rising or setting appear to most persons of from two to three times the diameter that they have when near the meridian. The cause of this phenomenon has been a source of speculation from the earliest times. Before optical science was thoroughly developed some thought that the image was really magnified by the vapors near the horizon. Not only is this incorrect, but in point of fact the sun is slightly and the moon measurably smaller when near the horizon, because they are farther off than when overhead.

“The true explanation is twofold. Human estimates of angular dimensions are dependent not merely on the angular dimensions themselves, but also on several extraneous circumstances. The case is analogous to our estimates of height, which are dependent primarily on the real height of the object, but secondarily upon its bulk. Thus, a pound of lead feels much heavier than a pound of feathers.

“One circumstance affecting our estimates of angular dimension is the linear dimension of the object itself. It was pointed out by Alhazen about nine hundred years ago that if we hold the hand at arm's length and notice what space it apparently covers on a distant wall, and then move the hand well to one side so that it is in front of some very near object, we shall find that it will appear to us decidedly smaller than the part of the wall which it previously covered. It is an analogous effect which makes the full moon when rising or setting appear larger than when it is well up in the sky. On the horizon we can compare it with trees and houses, and see how large it really is; overhead we have no linear scale of comparison.

“It is certain that this is not the only reason, however, nor even the chief one, that makes the moon appear larger when near the horizon. The same optical illusion appears when at sea, and it applies also to the constellations—for example, to Orion. When rising they appear decidedly larger than when near the meridian, and yet no comparison of their size with that of terrestrial objects is usually possible. There is evidently another circumstance

affecting our estimates of angular diameter. The explanation of this was first given by Clausius about thirty years ago, . . . but it has not as yet got into the text-books. The circumstance chiefly affecting our estimates of size depends on the angular altitude of the object under consideration.

“When we pass under an archway or under the limb of a tree we know that we are nearer to the object than we are when we see it under a lower altitude; at the same time it appears just as large to the average person angularly as it does when we are several feet farther away. We are, in fact, used, all our lives as we walk about, to see objects rapidly shifting their angular positions, yet not appearing as we pass them any larger than they do when we are slightly more distant from them. We thus always unconsciously make some compensation in our minds for the real changes in angular size that actually occur.

“If, now, the limb of the tree that we passed under, instead of really growing angularly smaller at the low altitude than it was when overhead, should remain of the same angular size in all positions, we should say that it looked larger at the low altitude. This is exactly what happens in the case of the heavenly bodies. Unlike all terrestrial objects, they are practically of the same real angular dimensions when on the horizon that they are in the zenith. We involuntarily apply to them the same compensation that we are accustomed to apply to terrestrial objects, and are thus naturally surprised to see that they appear larger at the lower altitude.”

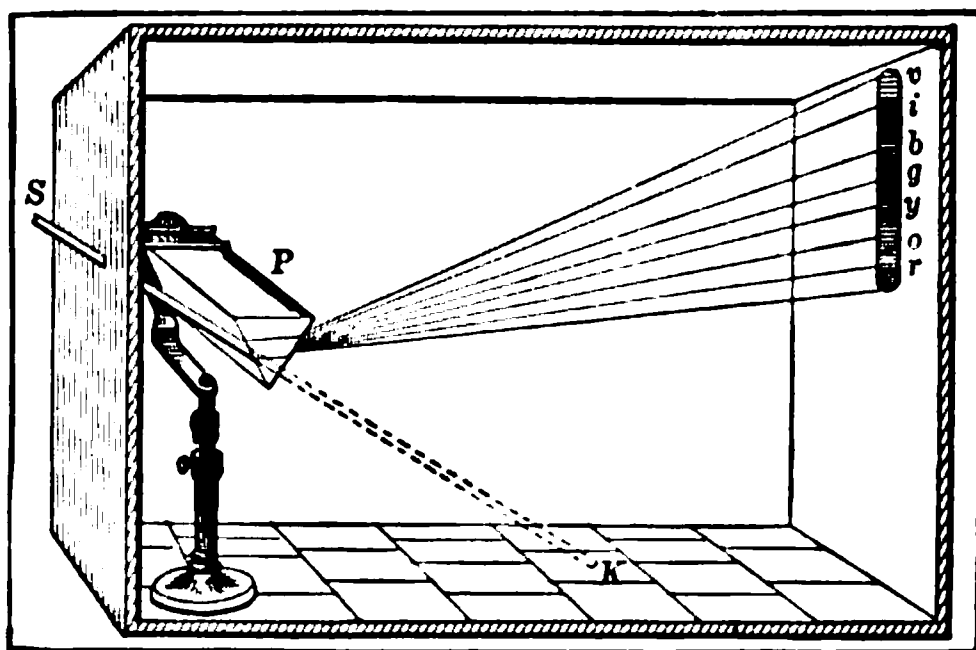


FIG. 362.—Formation of solar spectrum.

**Color.**—When a beam of sunlight passes through a prism it is separated by dispersion into its component colors, forming a solar spectrum (Fig. 362), the red rays being the least refracted, and the violet rays the most. The color depends upon the rapidity of vibration or the length of the waves; thus the red waves are the longest and the vibrations the least rapid, while the violet are the shortest and the vibrations the most rapid. In the following



table are given the wave-lengths for the center of each color in ten-millionths of a millimeter.

Red . . . . .	7000	Blue . . . . .	4960
Orange . . . . .	5972	Indigo . . . . .	4383
Yellow . . . . .	5808	Violet . . . . .	4059
Green . . . . .	5271		

There are rays, *calorific rays*, beyond the red rays whose wave-lengths are longer than the red, and others beyond the violet whose wave-lengths are shorter than those of the violet ; these latter are the *actinic rays* ; neither the calorific nor the actinic rays are visible.

If, after the dispersion, a second prism in reversed position (Fig. 363) is placed in the path of the colored rays, these will be

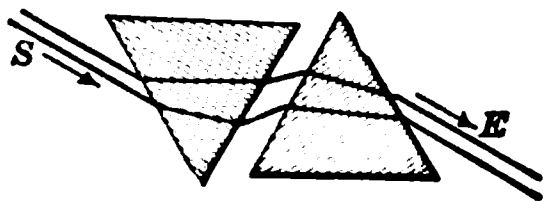


FIG. 363.—Reunion of colored rays to form white light.

reunited, and will emerge from the second prism as white light. This *synthesis* of light, or the composition of white light by the union of all the colors of the spectrum, may be brought about by the union of certain colors without using all of them ; thus red and bluish green will produce white light, as will also orange and light blue. Colors which when mixed produce white light are *complementary*. In the *color diagram* (Fig. 364) this relation is

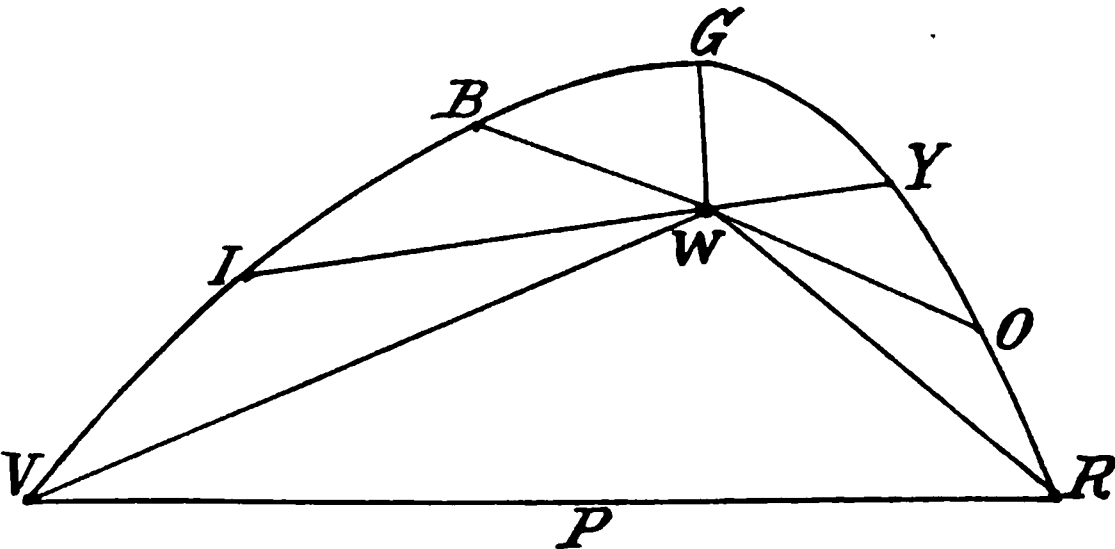


FIG. 364.—Color diagram.

made evident, the form of a triangle being selected around which to arrange the colors, rather than a circle, for the reason that they do not act equally as stimuli. Red, green, and violet are placed at the angles on the Young-Helmholtz theory of these being the primary colors—*i. e.*, the theory that the other colors are mixtures of these three colors. A reference to this diagram shows that red, green, and violet, represented by R, G, and V, make white, repre-

sented by w. The colors at the extremities of straight lines are complementary colors; orange and blue, O and B, make white, w. But neither B nor O is at the extremities of the line from R, but, if this line was continued, it would strike the curved line between B and G—i. e., red and bluish green are complementary colors. One can see also from this diagram what color results from the union of two others. Thus red and yellow will produce the intermediate color, orange; red and violet will produce purple, and this and green will produce white. If complementary colors are put beside each other, both colors are more pronounced; on the other hand, if colors which are not complementary are so placed, the colors are subdued.

It may be well here to refer to some of the fundamental facts in connection with colors, and for this purpose we shall quote statements and experiments from *Elements of Physics*, by Carhart and Chute. Color is not a property inherent in objects—i. e., bodies have no color of their own. Thus in the case of opaque bodies, the color which they appear to have depends upon the kind of light which they reflect. A red body is red because it absorbs the other colors of the spectrum than the red and reflects this color from its surface. If all the colors are reflected in proper proportion, the body appears white. This can be proved by looking through a glass prism at a piece of white paper 3 cm. long and 2 mm. wide, pasted on a piece of black cardboard several times larger, the edges of the prism being held parallel to the length of the strip. The image seen through the prism will be a spectrum similar to the solar spectrum. If a piece of red paper is substituted for the white paper, on looking through the prism the red end of the spectrum will be seen, but the other colors will be dim or absent. If a blue strip is looked at, the spectral image will show the blue, the other colors being lacking. In other words, white paper is white because it reflects all the colors in due proportion, while red paper reflects only red, and blue, only blue. If in the red of the solar spectrum a piece of red paper or ribbon is held, it will appear brilliantly red; elsewhere it will be nearly black; a piece of blue will appear blue in the blue of the spectrum, and there only. The color of opaque bodies varies as the light which falls upon them varies; thus if any fabric into which blue or violet enters, as purple and pink, is examined by artificial lights, all of which are deficient in blue and violet rays, its color will vary from that which it has in sunlight. It is on this account that matching colors by artificial light is so difficult.

*Transparent* bodies, on the other hand, are colorless when they absorb no light—i. e., transmit it all; or when they absorb all the colors in like proportion. It is the color or colors which are transmitted that give the color to transparent bodies. If one color is

absorbed, the color of the object will be the sum of the colors that are transmitted.

We are now prepared to discuss some of the facts which have been established in connection with the sensation of color. The union of the spectral colors to produce white light may be demonstrated by cutting out disks of colored paper (Fig. 365) and attaching them to a whirling machine (Fig. 366), or complementary colors may be combined in the same way with the same result; or, again, by using different colors various combinations may be made. This may be called a *physiologic mixture* of colors, and is thus explained: When the retina is exposed to a color, this produces a certain effect which remains even after the color which produced it has been removed; if, before the sensation caused by this color has disappeared, the retina is exposed to another color, the second color is superimposed upon the first, and if the two are complementary, the effect is that of white light, as when these

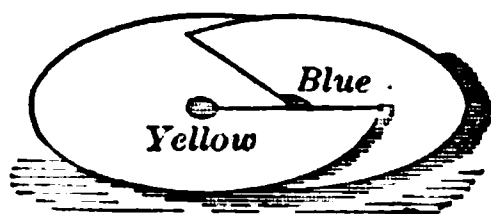


FIG. 365.—Disks of colored paper.

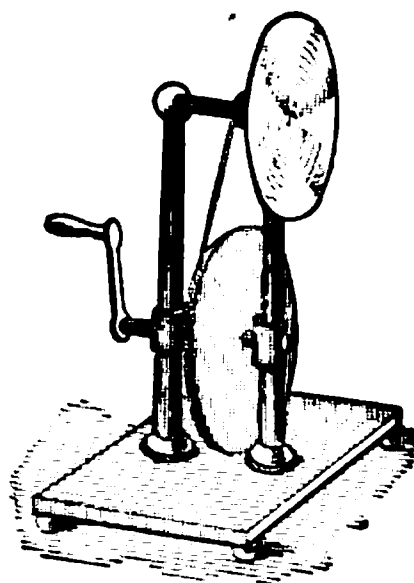


FIG. 366.—Whirling machine.

colors are combined by a prism. If the revolving disks contain all the spectral colors in due proportion, and are revolved rapidly enough, so that all the colors produce their effect on the retina before the sensation produced by any one has faded away, the effect of white light is produced, as when these colors are united by a prism.

*Mixing of Pigments.*—The effects just described as being produced by the physiologic mixture of colors cannot be produced by the *mechanical mixture* of pigments. Although blue and yellow when mixed upon the retina produce white, yet when blue and yellow pigments are mechanically mixed the resulting color is green and not white. If a broad line is drawn on a blackboard with a yellow crayon, and over this is drawn another line with a blue crayon, the resulting color will be green. This effect is explained in the following manner: The yellow crayon reflects not only yellow light, but also green light, and absorbs all the other colors. The blue crayon reflects not only blue, but also green, and

absorbs all the others. So that when the two are mixed, the only color which is not absorbed by the crayon is green, and therefore the line appears green.

Nor can the colors which are transmitted through transparent bodies be united to produce white light, or the combination which the mixture of colored lights produces on the retina, any more than can the pigments mentioned above, and the reason for this is obvious. If, for instance, sunlight is transmitted through red glass, all the rays which produce other colors than red are absorbed, and the red only being transmitted, gives the red color to the glass. If the same is done with green glass, only the green rays will be transmitted, all the other rays being absorbed. If now white light is transmitted through red glass, only the red will remain, and if this is transmitted through green glass, no light will come through, for green glass will not transmit the red rays, and the green rays have already been absorbed by the red glass. To produce white light or the various combinations of the spectral colors, the rays must fall upon the retina and the colors be mixed physiologically, the mixture producing effects which are interpreted by the brain.

*Young-Helmholtz Theory of Color.*—Inasmuch as this theory was advanced by both Young and Helmholtz, it bears the name of both. It is based on the view that there are in the retina three substances which are stimulated by the three primary colors, respectively, of red, green, and violet, and that when all three fall upon the retina in proper proportion the sensation of white is produced; and when any two of the three stimulate the retina, the effect is to produce some intermediate color, as, for instance, violet and green produce blue; red and green, yellow and orange; red and violet, purple. That such substances actually exist, there is no proof; the term "substance" is used for want of a better one. The term "fiber" is used by Helmholtz, and "red fibers," "green fibers," and "violet fibers" are spoken of. This theory supposes, also, that each of the primary colors stimulates to some extent all the three substances, but one is stimulated so much more than the others that the effect upon the others is not noticed. Especially marked is this differentiation of the red, green, and violet near the fovea centralis, and when the light is not too intense. If the light falls upon the portions of the retina near the ora serrata, or if that which falls on the retina in the neighborhood of the fovea is of very little or of very great intensity, all the rays seem to stimulate the three substances alike, for, under such circumstances, the colors of objects are not readily made out. The theory has been advanced that the power to distinguish colors resides in the cones, and that the stimulation of the rods by light gives the sensation of luminosity without color. Von Kries states that the rods are color-blind, their stimulation re-

sulting in the sensation of luminosity only ; that they are more easily stimulated than the cones, and are particularly responsive to waves of short wave-lengths ; and that they adapt themselves to light of varying intensity.

*Hering Theory of Color.*—This theory supposes the existence of three substances in the retina, and of six primary color sensations, arranged in pairs, white and black forming one pair, red and green another, and yellow and blue the third. These correspond, it will be noticed, to complementary color sensations. The three substances are the white-black, the red-green, and the yellow-blue. These substances are supposed to be susceptible of being affected in two opposite ways : In one a constructive or anabolic change is produced, and in the other a disintegrative or katabolic change. If, for example, all the spectral colors fall upon the white-black substance, katabolic changes occur in this substance producing the sensation of luminosity ; while if no light enters the eye, anabolic changes occur, with the effect of producing blackness. The red rays falling upon the retina produce katabolic changes in the red-green substance, producing the sensation of red, while the green produces anabolic changes, and the resulting sensation is that of green. Blue rays cause anabolic changes in the yellow-blue substance, and yellow rays cause katabolic changes in the same substance. These changes in the retinal substances produce the sensations of color when transmitted through the fibers of the optic nerve to the brain.

*Franklin Theory of Color-sensation.*—This theory supposes that the eye, in the early periods of development, possesses only the white-black or gray visual substance, and is therefore sensitive to luminosity only, and not to color. Later this substance becomes modified into the blue and yellow substance, and then into the red and green. For a further account of this theory the reader is referred to the *American Text-book of Physiology*, vol. ii., p. 337.

*Birch Modification of the Young-Helmholtz Theory.*—This experimenter has exposed the eye to sunlight in the focus of a burning-glass behind transparent screens of different colors, with the result of producing a temporary color-blindness. If a red screen is used, the eye is red-blind—*i. e.*, cannot distinguish the color, so that if scarlet is looked at, it appears black, while yellow appears green and purple appears violet. If a violet-colored screen is used, violet appears black ; purple appears crimson ; and green, a bright green. These effects are due to fatigue of the retina, so that the color to which the retina is exposed for a time ceases to stimulate, and that color ceases to be recognized while the other colors continue to stimulate. Birch found that after exposure to yellow the eye was blind not only to yellow, but to red and green also, which primary colors in the Young-Helmholtz theory produce yellow. He concludes that there are not only the three primary

colors red, green, and violet, but that blue must also be included as a primary color.

**Color-blindness or Daltonism.**—It is estimated that 4 per cent. of all males and 0.4 per cent. of all females are *color-blind*—*i. e.*, unable to recognize all colors; and this defect is congenital—*i. e.*, its possessor is born with it. It is said that it may be inherited also. Most of those who are color-blind are unable to distinguish between red and green, while some cannot tell green from blue, and others confound various colors. The name *Daltonism*, given to color-blindness, is derived from the name of the great chemist, Dalton, who when twenty-six years of age discovered that he was color-blind. By some writers the term “Daltonism” is used as a synonym for color-blindness in general, while others restrict its use to red-blindness. Dalton himself, in matching silk, would match red, pink, orange and brown with different shades of green; blue he would match with pink and violet, and lilac with gray. It was not Dalton, however, but a shoemaker, Harris by name, who discovered color-blindness, he himself being red-blind.

As already stated, most color-blind persons are either red-blind or green-blind. If a red-blind person looks at the spectral colors, those from the red to the green look green, while the extreme red end of the spectrum is invisible. The violet appears blue, and at the end of the green near the blue of the spectrum there appears to be a band of white or gray. To a green-blind person the spectral colors from red to yellow appear to be all yellow, but of different intensity: the green appears as a pale yellow, having in its middle a gray or a white band, while the violet appears blue. A report on color-blindness, made by the Royal Society, states that “to the green-blind, red and yellow are the same color; but the yellow being the brighter, he looks on red as degraded or darkened yellow. On the other hand, to the red-blind, green is brighter than yellow or orange, and these appear as degraded green.”

The explanation of color-blindness varies according to the theory of color-vision which is accepted. According to the Young-Helmholtz theory, a red-blind person is deficient in the red, and a green-blind person in the green, visual substance of the retina, or else, if these substances are present, all the rays, irrespective of their wave-lengths, stimulate them. In accordance with the Hering theory, those who are red-blind or green-blind lack the red-green visual substance and possess yellow-blue. On this theory there is no difference between red-blindness and green-blindness, but, as a matter of fact, this is not the case. If the Franklin theory is accepted, then the explanation in the case of the red- and green-blind would be that the white-black, or gray, visual substance had developed into the yellow-blue, but had been arrested in its development before the stage of red-green had



been reached. It may be said in conclusion that objections may be advanced to all the theories, and that no one accounts for all the observed facts.

*Holmgren Test.*—Inasmuch as color-blindness is so common a defect, and inasmuch as it may be a most serious one when the individual who suffers from it is engaged in a pursuit in which the lives of human beings may be jeopardized by his inability to distinguish colors, as a railway engineer or a pilot on a vessel, tests have been devised to determine its presence or absence. The one most commonly used is that of Holmgren, and consists in submitting to the one to be examined a lot of skeins of worsted of various colors, from which he is to select those which will match standard skeins of green and pink.

*Fatigue of Retina.*—When the retina has been exposed for some time to any color, it ceases to be sensitive to that color. It was this fact which led Helmholtz to the adoption of the theory of color-sensation which bears his name. He found that if the retina was exposed to a red light, it became fatigued for that color, and a yellow light appeared green; if exposed to a green light, and after it was fatigued for that color it was exposed to blue, the blue would appear violet. It was such experiments as these that led him to the opinion that there were three visual substances in the retina, and that there were three primary colors—red, green, and violet.

In a similar manner, if the retina is exposed to white, it becomes fatigued. Thus, if the eye is directed for a time to a piece of black paper placed on white paper, and then the black paper is removed, so that the eye sees only the white, the spot which was covered by the black will be more intensely white than the rest—for the reason that the portion of the retina upon which the light from the white paper falls when the other portion is covered by the black becomes fatigued, while the portion on which the rays from the black fall is not fatigued, and by contrast the white here appears whiter than does that of the other part of the paper.

*After-images.*—The white spot which is seen in the above experiment is a *negative after-image*—i. e., it is the opposite of the color which causes the fatigue, white being the opposite of black. Negative after-images are also produced when other colors are used. Thus, if a blue paper is imposed on white and the eye directed to it, and the blue then removed, the spot which had been covered by it appears yellow, blue and yellow being complementary colors. A negative after-image is always complementary in color to that which causes the retinal fatigue that produced it.

If the eye is directed to a brightly illuminated object, as the

sun, but not long enough to produce fatigue, and then closed, a bright spot of light is seen: this is a *positive after-image*. It remains bright for but a short time and then changes color, becoming greenish blue or bluish green, blue, violet, purple, and red, and then fading away entirely. It may be followed by a negative after-image.

**Visual Judgment.**—We have already referred to some visual judgments—as to form, size, distance, etc. (p. 584). It is a common saying that “seeing is believing,” and yet not one of the senses is more liable to deceive its possessor than that of sight. For instance, if the vertical and horizontal lines in Fig. 367 are compared, the vertical will immediately be pronounced the longer, and yet when accurately measured it will be found that each is exactly 4 cm. in length. This tendency to overestimate vertical lines is attributed to the relative weakness of the superior rectus muscle as compared with the muscles that move the eyeball horizontally. The difference is said to be from 30 to 50 per cent. in height and 40 to 53 per

FIG. 367.—To illustrate the overestimation of vertical lines.

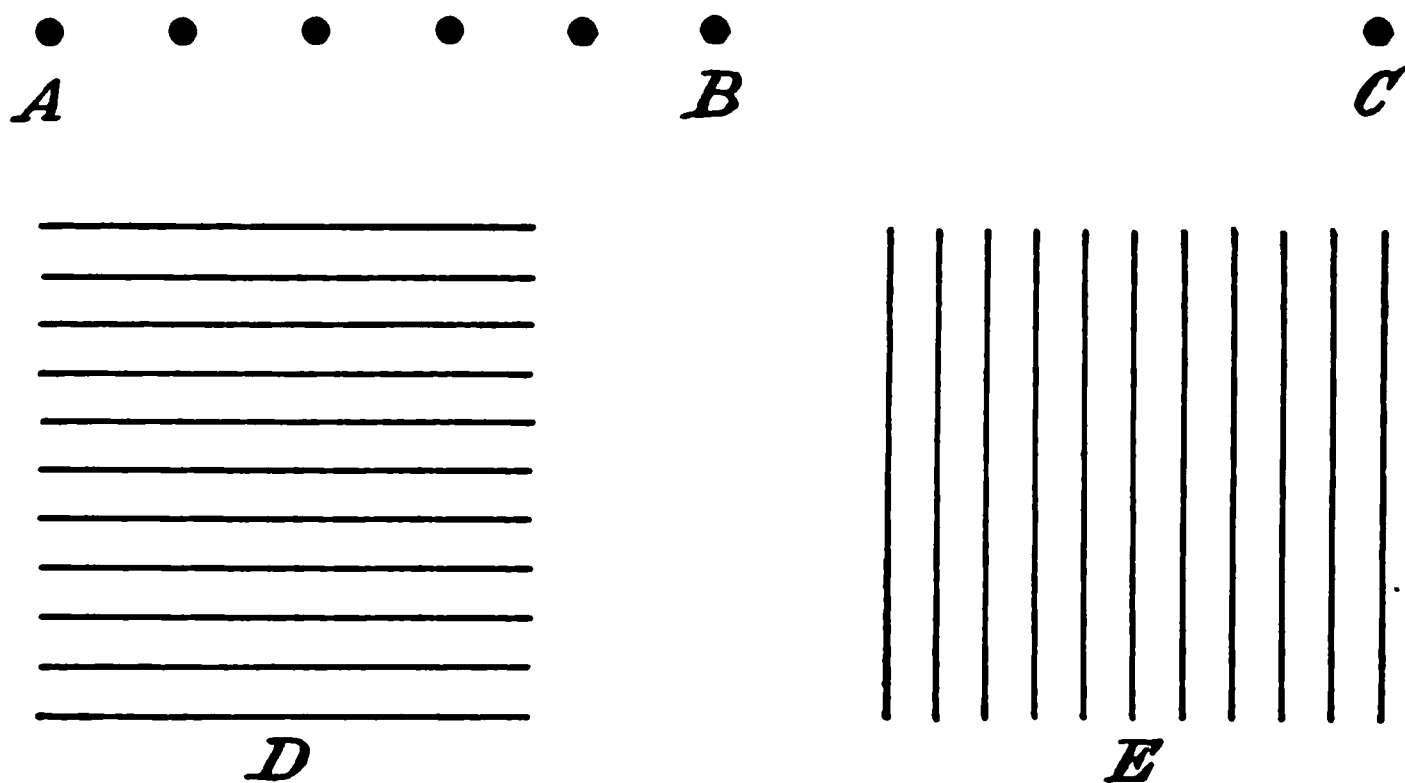


FIG. 368.—To illustrate the illusion of subdivided space.

cent. in area of cross-section; owing to this weakness a greater effort is required to turn the eyeball upward, and the effect upon the mind is that of turning it through a greater distance; hence vertical lines seem to be longer than they really are.



In Fig. 368 the space between A and B seems to be greater than that between B and C, and yet they are exactly the same. Any space like that between A and B which is subdivided seems larger than that which is undivided, as that between B and C. In Fig. 368 D appears to be higher than it is broad, and E broader than it is high.

So, too, Zöllner's lines (Fig. 369) are very illusory. The horizontal lines appear to be far from parallel, and yet if they are looked at from their ends, by turning the page sidewise, their

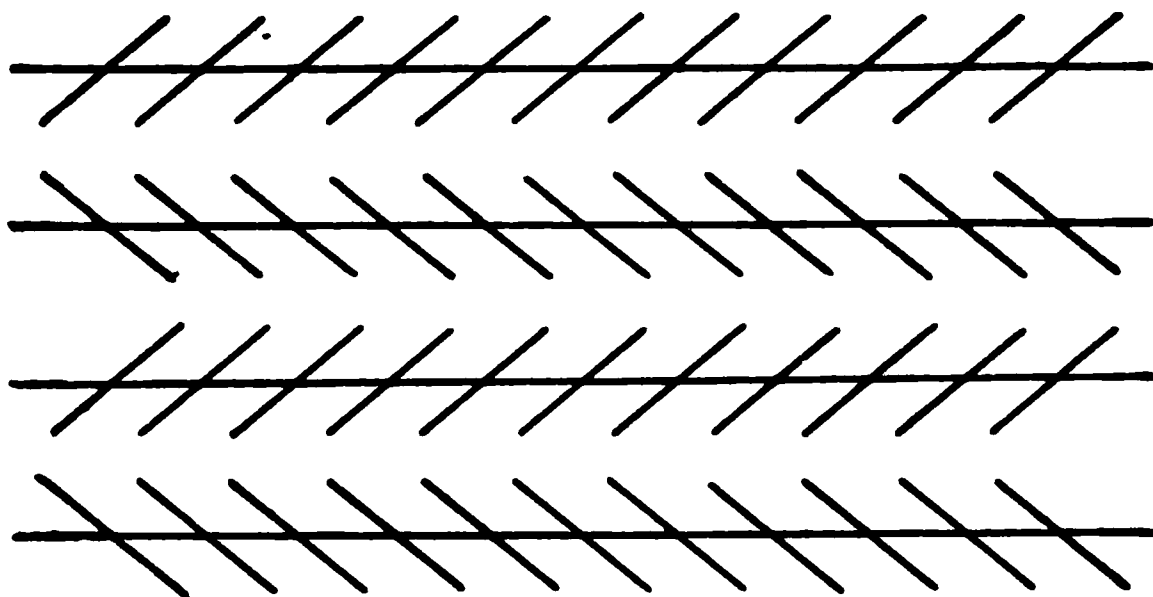


FIG. 369.—Zöllner's lines.

parallelism is at once apparent. This is explained by the fact that acute angles are apt to be overestimated and obtuse angles underestimated.

In Fig. 370 the straight line A appears shorter than the straight line B, though it is of exactly the same length.

Similar illusions might be multiplied almost indefinitely, and yet with all its imperfections the human eye is a wonderful organ. Some one has said that it is so defective from an optical standpoint that, had he ordered such a piece of apparatus from an optician



FIG. 370.—Illusion of space-perception (Bowditch).

and it had been delivered with as many defects, he would have returned it and refused to pay for it. It has also been said, in speaking of the crystalline lens, that an optician could make a better lens than Nature has furnished; but it has also been said that he could not make so good an eye. And finally, Dr. Bowditch, in his excellent discussion of "Vision," in the *American Text-book of Physiology*, well says: "When we reflect upon the difficulty of the problem which Nature has solved, of constructing an optical instrument out of living and growing animal tissue, we cannot fail to be struck by the perfection of the dioptric apparatus

of the eye as well as by its adaptation to the needs of the organism of which it forms a part."

**Appendages of the Eye.—Lacrimal Apparatus.**—To keep the conjunctiva (the mucous membrane covering the anterior seg-

**FIG. 371.**—Lacrimal and Meibomian glands, the latter viewed from the posterior surface of the eyelids. (The conjunctiva of the upper lid has been partially dissected off, and is raised so as to show the Meibomian glands beneath.) 1, free border of upper, and 2, free border of lower lid, with openings of the Meibomian glands; 3, Meibomian glands exposed, and 4, as seen through conjunctiva; 5, 6, lacrimal gland; 7, its excretory ducts, with 8, their openings in the conjunctival cul-de-sac; 9, conjunctiva (Testut).

ment of the sclerotic and the cornea and lining the lids) moist and in normal condition is the function of the *tears*. They are secreted by the *lacrimal gland*, a compound racemose gland lodged in a depression at the upper and outer portion of the orbit. Its ducts, about seven in number, open on the upper and outer half of the conjunctiva near its reflection over the eyeball. At the edge of the upper and lower eyelids, at their inner extremities, are openings, *puncta lacrimalia*, into which the tears pass after performing their function. These openings are the beginnings of the *canaliculi* (Fig. 372), which open into the *lacrimal sac*, or the dilated upper extremity of the *nasal duct*, which discharges at the inferior meatus of the nose, the opening here being partially closed by a fold of mucous membrane, the valve of Hasner.

**FIG. 372.**—1, Canaliculus; 2, lacrimal sac; 3, nasal duct; 4, plica semilunaris; 5, caruncula lacrimalis.

**Meibomian Glands.**—On the posterior surface of the eyelids,

beneath the conjunctiva, are the Meibomian glands (Fig. 371), thirty in number on the upper, and fewer on the lower lid. Their ducts open on the edges of the lids, and their secretion prevents the adhesion of the lids and the tears from running over them on to the cheeks.

**The Sense of Hearing.**—The ear (Fig. 373), the organ of hearing, consists of three subdivisions: (1) External; (2) middle; and (3) internal.

**External Ear.**—The external ear consists of the *pinna* or *auricle*, and the *external auditory canal* or *meatus*. The function of the

FIG. 373.—Diagram of organ of hearing of left side: 1, the pinna; 2, bottom of concha; 2', meatus externus; 3, tympanum; above 3, the chain of ossicles; 3', opening into the mastoid cells; 4, Eustachian tube; 5, meatus internus containing the facial (uppermost) and auditory nerves; 6, placed on the vestibule of the labyrinth above the fenestra ovalis; a, apex of the petrous bone; b, internal carotid artery; c, styloid process; d, facial nerve, issuing from the stylomastoid foramen; e, mastoid process; f, squamous part of the bone (Quain, after Arnold).

pinna is to collect the sound-waves and direct them to the external auditory canal, which they traverse to reach the membrana tympani. In some animals, such as the horse, the auricles are very important, enabling the animal to detect the direction from which sounds come, and they are capable of considerable movement; but in man they are not so important, although when the hearing is defective they are of assistance. That they are not essential to hearing is shown by the fact that when removed, hearing is not affected, and also by the fact that in birds, where they are absent, the sense of hearing is well marked.

The pinna (Fig. 375) is composed of yellow fibrocartilage covered by skin, although in some parts, as the *lobule*, the cartilage is absent. It is attached to the meatus and other parts by ligaments and muscles.

FIG. 374.—Semidiagrammatic section through the right ear: *G*, external auditory meatus; *T*, membrana tympani; *P*, tympanic cavity; *o*, fenestra ovalis; *r*, fenestra rotunda; *B*, semicircular canal; *S*, cochlea; *Vt*, scala vestibuli; *Pt*, scala tympani (Czermak).

*External Auditory Meatus.*—This canal, extending from the pinna to the membrana tympani, is about 3.2 cm. in length, the outer 1.3 cm. being of cartilage, except at the upper and back

Fos

† anthelix.

FIG. 375.—External ear.

part, where its place is taken by fibrous membrane. The inner 2 cm. is osseous. The entire canal is lined with skin, which in the cartilaginous portion of the canal contains sebaceous and perspiratory glands, their product being *cerumen* or *ear-wax* (p. 417). The skin lining the meatus also contains hair-follicles.

Inasmuch as in the examination of the ear and the treatment of its diseases it is necessary to introduce an aural speculum (Fig. 377), a knowledge of the direction and shape of the canal is essential. Its greatest diameter is at the external orifice and is vertical;

FIG. 376.—Muscles of the auricle: 1, attollens aurem; 2, attrahens aurem; 3, retrahens aurem; 4, helix major; 5, helix minor; 6, tragus, with 6', its accessory portion; 7, antitragicus; a, spine of helix; b, concha (Testut).

its smallest diameter is in the middle. At the tympanic end the greatest diameter is horizontal. The direction of the canal is obliquely forward, inward, and downward. Before introducing the speculum the helix of the ear is raised upward and backward so as to straighten the canal as much as possible.

**Middle Ear.**—This is called also the *tympanum* (Fig. 378).



FIG. 377.—Aural speculum.

**Membrana Tympani** (Fig. 379).—This membranous structure separates the *tympanic cavity* from the external auditory canal. Its shape is oval, and the direction of its long axis is downward and inward; its diameter along this axis is about 9 mm. It is composed of three layers: An external or *cuticular*, which is an extension of the integument that lines the external auditory canal; an internal, *mucous*, a continuation of the mucous membrane lining the tympanic cavity; and a middle, *fibrous*, made up of both fibrous and elastic tissues. There are two varieties of these fibers—*radiating*, which radiate from the center to the circumference; and *circular*, which form a ring at the circumference. The membrana tympani is set into a groove in a ring of bone, except at the upper part, where it is attached to the wall of the canal. This portion of the membrane is not so tense as

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FIG. 378.—Tympanum of left ear, with ossicles *in situ*: 1, suspensory ligament of malleus; 2, head of malleus; 3, epitympanic region; 4, external ligament of malleus; 5, processus longus of incus; 6, base of stapes; 7, processus brevis of malleus; 8, head of stapes; 9, *os orbiculare*; 10, manubrium; 11, Eustachian tube; 12, external auditory meatus; 13, *membrana tympani*; 14, lower part of tympanum (Morris).

1 2

FIG. 379.—Otoscopic view of left *membrana tympani*: 1, *membrana flaccida*; 2, 2', folds bounding the former; 3, reflection from processus brevis of malleus; 4, processus longus of incus (occasionally seen); 5, *membrana tympani*; 6, umbo and end of manubrium; 7, pyramid of light (Morris).

the rest, and has therefore received the name *membrana flaccida*. It is called also *Shrapnell's membrane*.

When a normal *membrana tympani* is viewed through an aural speculum, there is seen a triangular spot or *cone* or *pyramid* of light, whose apex is at the end of the manubrium or handle of the malleus, and whose base is at the circumference. The membrane is funnel-shaped, with the concavity toward the meatus, at the apex being attached the tip of the manubrium, and at this point on the outer surface is the *umbo* (Fig. 379).

**Tympanic Cavity** (Fig. 378).—In this cavity, which is situated in the petrous portion of the temporal bone, are the chains of bones, the ossicles, serving as a means of communication between the *membrana tympani* and the internal ear. It communicates posteriorly with the mastoid antrum and the mas-

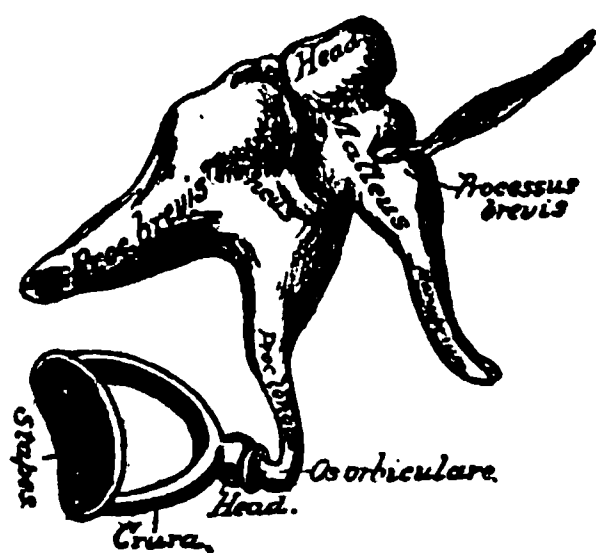


FIG. 380.—The ossicles of the left ear, external view (enlarged) (after Gray).

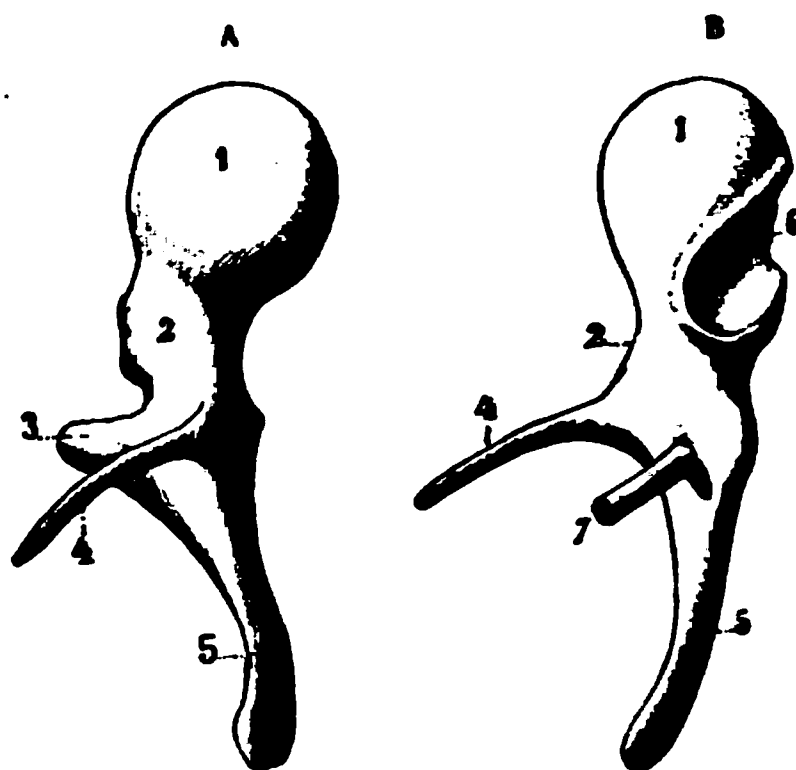


FIG. 381.—Malleus of the right side: A, anterior face; B, internal face; 1, capitulum or head of malleus; 2, cervix or neck; 3, processus brevis; 4, processus gracilis; 5, manubrium; 6, grooved articular surface for incus; 7, tendon of musculus tensor tympani (after Testut).

toid cells, and anteriorly with the pharynx by means of the Eustachian tube. Two openings, the fenestra ovalis and fenestra rotunda, give it communication with the internal ear. The roof of the tympanic cavity, the *tegmen*, is a very thin plate of bone, the only structure separating this cavity from that in which lies the brain. It is on account of this slight separation that inflammation of the middle ear sometimes extends to the brain. The tympanic cavity is lined by mucous membrane, which is covered with ciliated epithelium except over the ossicles and the *membrana tympani*.

**Ossicles** (Fig. 380).—These are three in number: the malleus, the incus, and the stapes.

**Malleus** (Fig. 381).—The malleus is about 18 mm. long, and consists of *head*, *neck*, *manubrium*, *processus gracilis*, and *processus brevis*.

The head has a general surface for articulation with the incus.

The manubrium or handle is attached to the membrana tympani. The processus gracilis is attached to the Gasserian fissure by bone and ligament. The processus brevis presses against the membrana flaccida, and its location is visible by inspection of the external



FIG. 382.—The incus of the right side: A, anterior face; B, internal face: 1, body of incus; 2, processus brevis; 3, processus longus; 4, articular surface for the malleus; 5, a convex tubercle, processus lenticularis, for articulation with stapes; 6, rough surface for attachment of the ligament of the incus (after Testut).

surface of the membrana tympani, through which it shows (Fig. 379). The malleus is held in place by ligaments (Fig. 384).

*Incus* (Fig. 381).—This is called also *ambos* and *anvil-bone*. The *body* is characterized by the presence of an articular surface for articulation with the malleus. It has two processes—*processus brevis* and *processus longus*. The processus brevis is attached by ligament to the margin of the opening that leads into the mastoid cells. The processus longus is nearly parallel with the handle



FIG. 383.—The stapes: 1, base; 2, anterior crus; 3, posterior crus; 4, articulating surface of head of the bone; 5, cervix or neck (after Testut).



FIG. 384.—Ligaments of the ossicles and their axis of rotation. The figure represents a nearly horizontal section of the tympanum, carried through the heads of the malleus and incus: M, malleus; I, incus; t, articular tooth of incus; lg.a. and lg.e., external ligament of malleus; lg.inc., ligament of the incus; the line a-x represents the axis of rotation of the two ossicles (from Foster, after Testut).

of the malleus and ends in a round projection, *os orbiculare* or *lenticular process*, which articulates with the head of the stapes. During fetal life the *os orbiculare* exists as a separate bone.

*Stapes* (Fig. 383).—This bone is so called from its resemblance



to a stirrup. It consists of a *head*, which articulates with the os orbiculare; a *neck*, into which the stapedius muscle is inserted; and two *crura*, which are connected with the *base*, this being attached by ligamentous tissue so as to close the fenestra ovalis.

*Ligaments of the Ossicles.*—The ossicles are connected with one another, and also with the walls of the tympanum, by ligaments (Fig. 384). One of these, the anterior ligament of the malleus, was at one time supposed to be a muscle and was described under the name *levator tympani*.

*Muscles of the Ossicles.*—These are two in number—tensor tympani and stapedius.

*Tensor Tympani.*—This muscle lies in a bony canal which is above the canal containing the Eustachian tube, and separated from it by the *processus cochleariformis*, a thin plate of bone. It has its origin from the petrous bone, the cartilaginous portion of the Eustachian tube, and the bony canal in which it lies. Its tendon enters the tympanum and bends at almost a right angle around the end of the *processus cochleariformis*, and is inserted into the manubrium near the neck. Its nervous supply is a branch from the otic ganglion. When this muscle contracts, the membrana tympani is drawn inward and made more tense.

*Stapedius.*—This muscle arises from the interior of the pyramid which is situated just behind the fenestra ovalis, and just below the opening of the mastoid antrum, and its tendon passes out at an opening in the apex; it is inserted into the neck of the stapes. Authorities do not agree as to the effect of the contraction of this muscle. Gray says that "it draws the head of the stapes backward, and thus causes the base of the bone to rotate on a vertical axis drawn through its own center; in doing this the back part of the base would be pressed inward toward the vestibule, while the fore part would be drawn from it. It probably compresses the contents of the vestibule."

Sewall, in the *American Text-Book of Physiology*, says: "Contraction of the muscle would cause a slight rotation of the stapes round a vertical axis, so that the hinder part of the foot of the ossicle would be pressed more deeply into the fenestra, while the remaining portion would be drawn out of it. Its action probably reduces the pressure in the cavity of the perilymph, and thus is antagonistic to that of the tensor tympani." The nervous supply of this muscle is the tympanic branch of the facial, which reaches the muscle through a canal in the pyramid which communicates with the aquæductus Fallopii.

**Eustachian Tube** (Fig. 385).—Through this channel the tympanum is in communication with the pharynx. It is about 36 mm. in length, and passes downward, forward, and inward.\* It begins in the lower part of the anterior wall of the tympanum, and is bony for about 12 mm. It then becomes cartilaginous, and

remains so throughout the rest of its course. It is lined by mucous membrane, the epithelium of which is ciliated. The direction of the motion of these cilia is from the tympanum to the pharynx, so that the secretion of the membrane lining the tympanum will escape into the pharynx. Its opening in the pharynx is ordinarily closed, except during the act of swallowing, when it momentarily opens; or it may be made to open by closing the mouth, holding the nostrils closed with the thumb and finger, and forcibly blowing. The pharyngeal opening is at the upper lateral part of the pharynx behind the inferior turbinated bone. There

Portion  
chian  
from ;

Mucosa of the  
pharynx.

Glands.

FIG. 385.—Cross-section of the Eustachian tube with its surrounding parts;  $\times 12$  (from a preparation by Professor Rüdinger).

is a band of muscular tissue, the *dilatator tubæ*, which joins the tensor palati.

**Mastoid Antrum.**—This is a cavity which opens into the *attic* or *epitympanic recess*, an extension upward and backward of the tympanic cavity. It is in this recess that the head of the malleus and a part of the incus are situated. The antrum communicates with the *mastoid cells* in the mastoid process. Antrum and cells are lined by mucous membrane which is continuous with that of the tympanum. This extension of the mucous membrane explains how inflammation of the middle ear may extend to the mastoid cells.

**Fenestra Ovalis** (Fig. 386).—This is an oval opening in the internal wall of the tympanum into the vestibule of the internal

ear, and is closed by the stapes, an annular ligament uniting the bone to the fenestra.

**Fenestra Rotunda.**—This opening, also on the internal wall of the tympanum, leads into the cochlea of the internal ear. It is

5 9 10

**FIG. 366.**—Right bony labyrinth, viewed from outer side: the figure represents the appearance produced by removing the petrous bone down to the denser layer immediately surrounding the labyrinth: 1, 2, 3, the superior, posterior, and external or horizontal semicircular canals; 4, 5, 6, the ampullæ of the same; 7, the vestibule; 8, the fenestra ovalis; 9, fenestra rotunda; 10, first turn of the cochlea; 11, second turn; 12, apex (from Quain, after Sömmerring).

**FIG. 367.**—Interior view of left bony labyrinth after removal of the superior and external walls: 1, 2, 3, the superior, posterior, and external or horizontal semicircular canals; 4, fovea hemi-elliptica; 5, fovea hemispherica; 6, common opening of the superior and posterior semicircular canals; 7, opening of the aqueduct of the vestibule; 8, opening of the aqueduct of the cochlea; 9, the scala vestibuli; 10, scala tympani; the lamina spiralis separating 9 and 10 (from Quain, after Sömmerring).

closed by the *membrana tympani secundaria*, which is made up of an external or mucous layer, a continuation of that lining the tympanum; and an internal or serous, a continuation of that lining the cochlea; between these two is a third or fibrous layer. Be-

tween the two fenestræ is the *promontory*, a prominence caused by the projection of the first turn of the cochlea.

**Internal Ear** (Figs. 386, 387).—This is called also the labyrinth. It consists of a bony part, the *osseous labyrinth*, in which is contained the *membranous labyrinth*.

**Osseous Labyrinth**.—This is made up of three parts: The vestibule, the semicircular canals, and the cochlea, all of which are connecting cavities in the petrous bone. These cavities not only communicate with one another, but through the fenestra ovalis and fenestra rotunda the osseous labyrinth is in communication with the tympanum; and through the meatus auditorius internus with the cranial cavity.

**Vestibule**.—This cavity is at the inner side of the tympanum, and opens anteriorly into the cochlea and posteriorly into the semicircular canals. It is about 5 mm. in diameter, and on its outer wall communicates with the tympanum through the fenestra ovalis, which is closed by the stapes and its annular ligament. The *fovea* or *fossa hemispherica* is a depression on the anterior wall. This is perforated anteriorly, forming the *macula cribrosa*, and through these perforations the auditory nerves pass to the sacculæ. Behind the fovea hemispherica is a vertical ridge, the *crista vestibuli*. The *aquæductus vestibuli* communicates with the vestibule by an opening at the posterior part of the inner wall. Through this canal pass a vein and the *ductus endolymphaticus*. The *fovea* or *fossa hemi-elliptica* is an oval depression on the roof of the vestibule. Between it and the fovea hemispherica is the *crista vestibuli*. Posteriorly the semicircular canals open into the vestibule, while the opening into the cochlea, *apertura scalæ vestibuli cochleæ*, is situated anteriorly.

**Semicircular Canals**.—These are three in number, situated behind the vestibule and above it. Each has a diameter of about 1.5 mm., except at one end, the *ampulla*, where the diameter is 2.5 mm., and each canal is so arranged as to be at right angles to the others. The *superior* is vertical and at *right angles* to the posterior surface of the petrous bone; its ampullated extremity opens into the vestibule, while its other extremity joins with the non-ampullated extremity of the *posterior* canal, and these open into the vestibule by one common opening. The *posterior* canal is also vertical, but *parallel* with the posterior surface of the petrous bone. Its ampullated extremity opens into the vestibule. The *external* canal is horizontal, and both its extremities open into the vestibule. It will be seen that the three canals have but five openings into the vestibule, one opening being common to two canals.

**Cochlea** (Fig. 388).—The cochlea is situated in front of the vestibule, with its apex directed outward, forward, and downward, its base corresponding to the internal auditory meatus. It is 5

mm. long and 9 mm. broad at its base. It consists of an axis, the *modiolus* or *columella*, which runs through the entire structure, from the base to the apex; around the modiolus runs the spiral canal. At the base the modiolus is perforated to transmit filaments of the cochlear branch of the auditory nerve, and through it extends the *canalis centralis modioli*, which transmits a nerve and an artery.

The *spiral canal* is about 2 mm. in diameter and 3.3 cm. in length. It makes two and three-fourth turns, clockwise—i. e.,

FIG. 388.—The cochlea and vestibule as seen from above: *A*, cochlea; *B*, vestibule; *C*, internal auditory canal; *D*, tympanum. 1, Lower border of fenestra ovalis; 2, vestibulotympanic cleft; 3, fossa hemispherica; 4, fossa hemi-elliptica; 5, fossa cochlearis; 6, orifice of aqueduct of vestibule; 7, lower orifice of posterior semicircular canal; 8, non-ampullary orifice of the external semicircular canal; 9, scala tympani; 10, scala vestibuli; 11, cupola; 12, lamina spiralis, with 12', its vestibular origin; 12'', its external border; 13, helicotrema (Testut).

in the direction taken by the hands of a clock—around the modiolus. At the apex the canal terminates in the *cupola*. This canal is partially divided into two by a bony septum, the *lamina spiralis*, which consists of two thin plates of bone between which are minute canals for the transmission of nerve-fibers. The lamina spiralis extends from the modiolus only about half-way toward the outer wall of the spiral canal. In the recent state there is a membrane, the *membrana basilaris*, extending from the edge of the lamina spiralis to the outer wall, dividing the canal into two parts, the lower being the *scala tympani*, while the

upper is again subdivided by a membrane, the *membrane of Reissner*, into two canals: that between the inner wall of the cochlea and this membrane being the *scala vestibuli*; and that between the outer wall and the membrane of Reissner, having the *membrana basilaris* as its base, the *scala media*, *ductus cochleæ*, or *canalis cochleæ*. This latter is in reality a part of the membranous labyrinth, not of the osseous, but it is somewhat more convenient to describe it at this point. At the apex of the cochlea the lamina spiralis ends in the *hamulus*, a hook-like process, and here the *scala vestibuli* and *scala tympani* communicate, the opening being the *helicotrema*. At the junction of the lamina spiralis and the modiolus, and winding around the latter, is the *canalis spiralis modioli*, which lodges the *ganglion spirale*, an enlargement of the cochlear nerve containing ganglion-cells. From this are given off the nerves to the organ of Corti.

The *scala vestibuli* communicates with the vestibule at its lower end. The *scala tympani* at its lower end terminates at the *fenestra rotunda*, which is closed by the *membrana tympani secundaria*.

*Aquæductus Cochleæ*.—This is a small canal running from the *scala tympani* to the basilar surface of the petrous bone which transmits a vein from the cochlea that joins the internal jugular vein.

*Lining of Osseous Labyrinth*.—All the cavities of the osseous labyrinth are lined by a fibroserous membrane, regarded by some as periosteum; this membrane also covers the *fenestra ovalis* and *fenestra rotunda*. On its inner surface is a layer of epithelium which secretes the *perilymph*, a watery fluid containing mucin, which fills so much of the osseous labyrinth as is not occupied by the membranous labyrinth.

*Membranous Labyrinth* (Fig. 391).—The membranous labyrinth is contained within the osseous, and is, to a certain extent, a duplication of it. Its walls consist of three layers: 1. An *external*, which is made up of fibrous tissue, rather loose in structure, in which are blood-vessels and pigment-cells similar to those in the retinal pigmentary layer; 2. A *middle* layer, thicker than the external, and somewhat like the hyaloid membrane of the eye; and 3. An *internal*, composed of polygonal nucleated epithelium which secretes the *endolymph* or *liquor Scarpæ*, a fluid similar in composition to the perilymph, and contained within the membranous labyrinth, as the perilymph is within the osseous.

The membranous labyrinth consists of the utricle and saccule, which are contained in the vestibule; the three membranous semicircular canals, and the canal of the cochlea or *scala media*.

The utricle, saccule, and membranous semicircular canals are attached on one side to the wall of the osseous labyrinth, and from the opposite side are given off bands of fibrous tissue which hold

them to the corresponding wall of the osseous labyrinth. In these bands are the blood-vessels and the fibers of the auditory nerve which are distributed to the utricle, saccule, and membranous semicircular canals.

*Utricle.*—The *utricle* or *utriculus* is situated in the upper and back part of the vestibule at the fovea hemi-elliptica, and is oblong in shape. It communicates posteriorly with the membranous semicircular canals by five openings, and from it passes a small canal which unites with one from the saccule, the two forming the *ductus endolymphaticus*. Branches of the auditory nerve pierce the wall of the utricle at one point, and here the tunica propria is thickened, and the epithelium consists of columnar cells upon which are long, stiff, tapering hairs, around which the axie-cylinders of the auditory nerve-fibers ramify. Schäfer, to whom we are indebted for this description, says that these are like the rod- and cone-elements of the retina, the bipolar cells of the olfactory membrane, and the gustatory cells of the taste-buds—sensory or nerve-epithelium cells. Between the hairs are nucleated cells,

FIG. 389.—Section of macula of utricle, human: *n. utr.*, bundles of the utricular branch of the eighth nerve; *h*, auditory hairs; *p.l.s.*, perilymphatic space (G. Retzius).

*fiber-cells* of Retzius, which rest upon the basement-membrane, and are connected at their free extremity with a cuticular membrane through which the auditory hairs project. The auditory hairs do not project free into the endolymph, but into a soft, mucus-like substance of a dome-like form in the ampullæ, and which in the saccule and utricle has a mass of calcareous particles, *otoliths*, embedded in it. The otoliths are also called *otoconia* and *ear-stones*, and are minute crystals of calcium carbonate. The thickening of the tunica propria with the modified cells, etc., just described, forms the *macula acustica* in the utricle and saccule (Figs. 389, 390). In the ampullæ of the semicircular canals the columnar cells and auditory hairs are upon a ridge, and here the structure is called *crista acustica*. The *cristæ* of the ampullæ have essentially the same structure as the *maculæ* of the utricle and saccule, save that the otoliths are absent.

*Saccule.*—The *saccule* or *sacculus* is globular, smaller than the utricle, being about 3 mm. by 2 mm. in diameter, and lies in the fovea hemispherica. It receives nervous filaments derived from

the auditory nerve, which terminate, as already described, in a macula acustica in which are otoliths, and it gives off a small canal which, uniting with that coming from the utricle, forms the

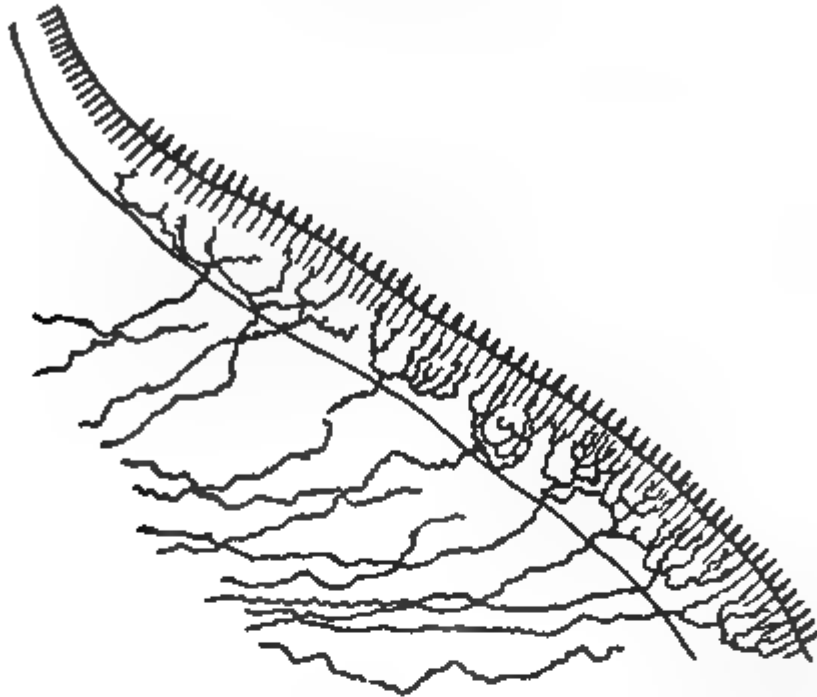


FIG. 390.—Nerve terminations in macula; Golgi method (G. Retzius).

ductus endolymphaticus. On the opposite side is a similar canal, 1 mm. long and 0.5 mm. wide, the *canalis reuniens* (Fig. 391), by

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FIG. 391.—Diagram of right membranous labyrinth seen from the external side: 1, utricle; 2, 3, 4, superior, posterior, and horizontal semicircular canals; 5, saccule; 6, ductus endolymphaticus, with 7, 7', its twigs of origin; 8, saccus endolymphaticus; 9, canalis cochlearis, with 9', its vestibular cul-de-sac, and 9'', its blind extremity; 10, canalis reuniens (after Testut).

which it is in communication with the scala media or canalis cochlearis.

*Ductus Endolymphaticus*.—This canal, formed by the union of the canals from the utricle and saccule, is lodged in the aquæductus



vestibuli. It terminates in a dilated and flattened *cul-de-sac*, which lies within the cranial cavity between the layers of the dura mater.

*Membranous Semicircular Canals.*—These are three in number, in shape like the osseous canals, but are only about one-third their diameter; they open by five apertures into the utricle. The lining of the canals forms papilliform elevations (Fig. 392). In each ampulla is the ridge, *criata acustica*, already described (p. 610).

Membranous semicircular canal.

Epithelium of the  
membranous  
canal.

Ligament of  
canal.

Bone.

Blood-vessel.

FIG. 392.—Transverse section through an osseous and membranous semicircular canal of an adult human being: *a*, connective-tissue strand representing a remnant of the embryonic gelatinous connective tissue. Such strands serve to connect the membranous canal with the osseous wall;  $\times 50$  (after a preparation by Dr. Scheibe) (Böhm and Davidoff).

*Canal of the Cochlea.*—For the following description we are indebted to Schäfer's *Essentials of Histology*: "The periosteum, a peculiar kind of connective tissue which covers the upper surface of the lamina spiralis, is thickened, forming the *limbus*, also called *limbus laminae spiralis*, and *denticulate lamina* by Todd and Bowman, and the edge is grooved, somewhat resembling the letter C, the upper part of which is the *labium tympanicum*; between these labia is the *sulcus spiralis* (Fig. 393). The membrana basilaris, already referred to (p. 608), extends from the labium tympanicum

to the outer bony wall of the cochlea, where it is enlarged, forming the *ligamentum spirale*. From the base of the labium vestibulare a membrane (*Reissner's membrane*) extends to the outer wall, above and nearly parallel with the membrana basilaris. Between this membrane and the membrana basilaris is the *ductus cochlearis* or *ductus auditorius*, and in this, situated upon the membrana basilaris,

FIG. 393.—Section through one of the turns of the osseous and membranous cochlear ducts of the cochlea of a guinea-pig: *l*, scala vestibuli; *m*, labium vestibulare of the limbus; *n*, sulcus spiralis internus; *o*, nerve-fibers lying in the lamina spiralis; *p*, ganglion-cells; *q*, blood-vessels; *a*, bone; *b*, Reissner's membrane; *Dc*, ductus cochlearis; *d*, Corti's membrane; *f*, prominentia spiralis; *g*, organ of Corti; *k*, ligamentum spirale; *i*, crista basilaris; *k*, scala tympani;  $\times 90$  (Böhm and Davidoff).

is the *organ of Corti*. The membrana basilaris is composed of stiff, straight fibers, estimated at 24,000 in number, which are embedded in a homogeneous stratum. It is much broader in the uppermost turns of the cochlea than in the lowest; the width being at the bottom, 0.21 mm.; in the middle, 0.34 mm.; and at the top, 0.36 mm."

*Organ of Corti* (Figs. 394, 395).—This consists of (1) the rods of Corti; (2) a reticular lamina; (3) outer hair-cells; (4) inner hair-cells.

FIG. 394.—Organ of Corti: at  $\pi$  the tectorial membrane is raised; *c*, outer sustentacular cells; *d*, outer auditory cells; *f*, outer pillar cells; *g*, tectorial membrane; *h*, inner sustentacular cells; *i, p*, epithelium of the sulcus spiralis internus; *k*, labium vestibulare; *e*, tympanic investing layer; *m*, outer auditory cells; *n, n*, nerve-fibers which extend through the tunnel of Corti; *o*, inner pillar cell; *q*, nerve-fibers; *b, b*, basilar membrane; *a*, epithelium of the sulcus spiralis externus; *r*, cells of Hensen; *s*, inner auditory cell; *l*, ligamentum spirale (after Retzius).

*Rods of Corti*.—These are of two kinds, the *inner*, of which there are 5600, and the *outer*, 3850 in number. They are both

*b*

FIG. 395.—Section of Corti's organ from guinea-pig's cochlea: *ST*, scala tympani; *TC*, tunnel of Corti; *a*, bony tissue or spiral lamina; *b, b*, fibrous tissue covering same continued as substantia propria of basilar membrane; *c, c*, protoplasmic envelope of Corti's pillars (*e, e*); *d*, endothelial plates; *f*, heads of pillars containing oval areas; *g*, head plates of pillars; *h, h'*, inner and outer hair-cells; *m*, membrana reticularis; *k, l*, cells of Hensen and Claudius; *n, n*, nerve-fibers; *i*, cells of Deiters (after Piersol).

stiff, striated cells; the shape of the inner has been compared to that of the human ulna, with a depression like the sigmoid cavity and processes like the coronoid and olecranon; the shape of the

outer, to the head and neck of a swan. The feet of the rods rest on the basilar membrane, and here may be seen the cells from which they are derived; their heads are joined together, the head of the outer fitting into the depression of the inner. Inasmuch as the rods are arranged in a series by the side of one another, this arrangement makes a *tunnel*, the floor of which is the basilar membrane, while the sloping sides are made by the inclined rods. From each outer rod projects a *phalangeal process*.

*Reticular Lamina*.—This is also described under the name *membrane of Kölliker*, and consists of a network in which are perforations. It is made up of “minute fiddle-shaped cuticular structures,” *phalanges*, and through the perforations which are between these phalanges project the cilia of the outer hair-cells.

*Outer Hair-cells*.—These are 12,000 in number, and are arranged in three or four rows external to the outer rods, each cell being surmounted by a bundle of short *auditory hairs* which projects through one of the perforations of the reticular lamina. From the other extremity is given off a fine process which is attached to the *membrana basilaris*. Between the rows of hair-cells are the *cells of Deiters*, regarded as supporting cells, with their bases on the *membrana basilaris* and their tapering processes attached to the reticular lamina.

*Inner Hair-cells*.—These, 3500 in number, are arranged in a single row, internal to the internal rods, and, like the outer hair-cells, possess auditory hairs. The epithelial cells next to the outer hair-cells are long and columnar, but cubical over the outer wall of the canal of the cochlea; they are much the same on the inner side of the inner hair-cells, but are of the pavement variety on the membrane of Reissner.

*Membrana Tectoria*.—This structure, called also the *membrane of Corti*, is soft and fibrillated. It extends from the limbus, and “lies like a pad over the organ of Corti,” probably resting on the auditory hairs. Retzius states that it is attached to the reticular lamina. Gray says that it is blended with the *ligamentum spirale* on the outer wall of the spiral canal.

*Auditory Nerve*.—The auditory nerve divides into two branches at the bottom of the *meatus auditorius internus*; these are the cochlear and vestibular.

*Cochlear Branch of Auditory Nerve*.—This is called also *cochlear nerve*. At the base of the columella or modiolus of the cochlea it subdivides into filaments, which run through it in canals. When they reach the *lamina spiralis* they form at its base the *ganglion spirale*, composed of a plexus of the nervous filaments with ganglion-cells. From the *ganglion spirale* delicate filaments are given off, which pass between the plates of the *lamina spiralis* until they reach the *sulcus spiralis*, where they pass out to the organ of Corti. Waldeyer states that here they divide

into two groups—one going to the inner hair-cells, the other to the outer. Schäfer says that “after traversing the spiral lamina they emerge in bundles, and the fibers then, having lost their medullary sheath, pass into the epithelium of the inner hair-cell region. Here some of them course at right angles, and are directly applied to the inner hair-cells, whilst others cross the tunnel of Corti, to become applied in like manner to the outer hair-cells and the cells of Deiters; but there does not appear to be any continuity between the nerve-fibrils and the cell-substance.”

*Vestibular Branch of Auditory Nerve.*—This is often spoken of as the *vestibular nerve*. It divides into three branches: 1, *superior*, which is distributed to the utricle and the ampullæ of the external and superior semicircular canal; 2, *middle*, which is distributed to the saccule; and 3, *inferior*, which is distributed to the ampulla of the posterior semicircular canal.

**Physiology of Hearing.**—Sound is defined by the *Standard Dictionary* as: “1. The sensation produced through the organs of hearing. 2. The physical cause of this sensation; waves of alternate condensation and rarefaction passing through an elastic body, whether solid, liquid, or gaseous, but especially through the atmosphere.”

Bodies which emit sound are called *sonorous bodies*, and are at the time in a state of vibration. Thus a tuning-fork when set in vibration produces in the air around it a series of condensations and rarefactions which form “concentric spherical shells of air of different densities. Each air particle swings to and fro in a very short path along the radius of the sphere—that is, the vibrations are longitudinal” (Carhart and Chute).

These waves are *sound-waves*, and when they enter the external auditory meatus they set up vibrations in the membrana tympani. Through the ossicles these vibrations are transmitted to the perilymph. The base of the stapes, which, with its annular membrane, closes the fenestra ovalis, communicates these vibrations to the perilymph in the scala vestibuli, along which waves of the fluid travel, passing through the helicotrema and down the scala tympani to the fenestra rotunda, the membrana tympani secundaria being pressed out as each wave reaches it. In this course the waves of perilymph pass over the membrane of Reissner as they travel up the scala vestibuli, and under the membrana basilaris as they return down the scala tympani, thus setting up corresponding vibrations in the endolymph which fills the membranous cochlea.

The external ear collects the sound-waves, and in some animals, as in the horse, is very useful in determining the direction from which sounds come; these animals, by virtue of muscles attached to the ear, can move it in all directions. In man such muscles exist, but in a relatively undeveloped form, and are not under the

control of the will to any extent, although some individuals can produce a slight to-and-fro motion of the auricle. When the hearing is imperfect the hand is sometimes applied to the ear in such manner as to increase its projection from the side of the head and to supplement it, so as to collect more sound-waves than would otherwise enter the meatus.

In order that the membrana tympani should respond to the many tones and shades of tones which reach it, it is important that the pressure upon the internal and external surfaces should be the same, and this is effected by the passage of air through the Eustachian tube, so that in going from an atmosphere of one density into that of another the equilibrium is thus maintained. The pharyngeal aperture of the tube, ordinarily closed, is opened by the action of the tensor palati at each act of swallowing.

When the membrana tympani moves inward, the manubrium of the malleus moves inward also, and with it the incus, the articulation between these two ossicles being such that in this inward movement they move as one. In speaking of this articulation Helmholtz says: "In its action it may be compared with the joints of the well-known Breguet watch-keys, which have rows of interlocking teeth, offering scarcely any resistance to revolution in one direction, but allowing no revolution whatever in the other." When the membrana tympani is forced strongly outward, the manubrium glides in the joint, and the incus follows it for but a short distance; if this was not so, in such movements of the membrana tympani the stapes would be pulled out of the fenestra ovalis, and severe, if not irretrievable, injury would result. This extreme outward movement of the membrana tympani might result from increased pressure within the tympanum or diminished pressure in the external auditory meatus. These movements of the drum-membrane and the stapes are at most but limited; the maximum for the membrane being only from  $\frac{1}{12}$  to  $\frac{1}{8}$  mm., and of the stapes from about  $\frac{1}{18}$  to  $\frac{1}{14}$  mm. The amplitude of movement of the latter may be only  $\frac{1}{10000}$  mm.

Thus is accomplished the conversion of sound-waves into waves of perilymph. Helmholtz says: "The mechanical problem which the apparatus within the drum of the ear had to solve was to transform a motion of great amplitude and little force, such as impinges on the drum-skin, into a motion of small amplitude and great force, such as had to be communicated to the fluid in the labyrinth." A study of the ossicles (Fig. 396) shows that their movement is around the axis of rotation, *a-x* in Fig. 397. If the distance from this axis to the tip of the manubrium is measured, it will be found to be one and one-half times that from the axis to the end of the long process of the incus, with which the stapes articulates, so that the amplitude of the movement of the stapes

will be but two-thirds that of the tip of the manubrium, but will have one and one-half times its force.

The action of the tensor tympani and that of the stapedius have been already described (p. 604).

It is interesting to note that sound may be conducted to the internal ear through the bones of the skull so as to cause the sensation of hearing. Thus if a vibrating body, as a tuning-fork, is held between the teeth, it can be heard though the ears are closed; indeed, it sounds more loudly when the ears are closed than when they are open. The sound is conducted by the bones to the internal ear, and also, doubtless, some of the sound is due to vibrations of the membrana tympani.

This fact is made use of in the *audiphone*, a fan-like device held in the teeth by the deaf. If the essential portions of the auditory apparatus are so diseased as to cause deafness, no such device as the audiphone will be of any use.

**Theories of Hearing.**—Two theories have been advanced to

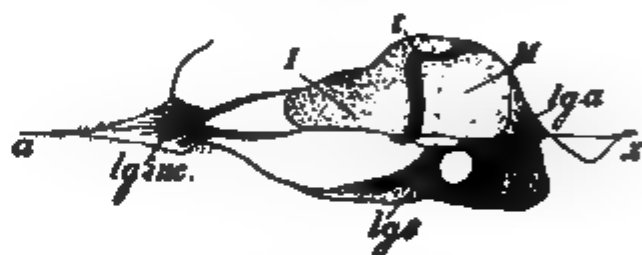


FIG. 396.—The chain of auditory ossicles, anterior view: 1, head of malleus; 2, long process of incus; 3, stapes (after Testut).

FIG. 397.—Ligaments of the ossicles and their axis of rotation. The figure represents a nearly horizontal section of the tympanum, carried through the heads of the malleus and incus: *M*, malleus; *I*, incus; *t*, articular tooth of incus; *lg.a.* and *lg.e.*, external ligament of malleus; *lg.inc.*, ligament of the incus; the line *a-x* represents the axis of rotation of the two ossicles (from Foster, after Testut).

explain the physiology of hearing: (1) The piano theory and (2) the telephone theory.

**The Piano Theory.**—This is by far the older, and may be regarded as the theory usually held to explain what takes place in the cochlea. The cochlear division of the auditory nerve sends into the modiolus of the cochlea branches that pass in between the plates of the lamina spiralis, where they form a plexus in which are ganglion-cells, from which the nerve-filaments pass to the organ of Corti, terminating, it is believed, in the hair-cells.

The waves already referred to as being set in motion in the *endolymph* pass over and under these cells, with which the nerve-filaments are connected, and cause the basilar membrane on which they rest to vibrate. This motion is communicated to the outer rods of Corti, which in turn pass it to the hairs of the special auditory cells through the medium of the perforated membrane, and from

there it passes to the nerves. Here it is converted into impulses which are transmitted to the brain, where sound is produced.

It has been supposed that the rods of Corti are so arranged as to vibrate with particular tones, one rod for each tone, but it is doubtful whether such a differentiation can be made out in the auditory apparatus. The rods are not present in the ears of birds, and there is no reason to believe that birds cannot appreciate musical tones. In the basilar membrane there are fibers enough to respond to all the notes that can be appreciated—that is, from 33 waves to 38,000 waves in a second. It is more probable that the rods simply act as levers to communicate the vibrations of the fibers of the basilar membrane to the terminal nerve-filaments in the auditory cells.

Just how one is able to distinguish the differences in the intensity (loudness), pitch, and quality of sounds is not understood. The explanation most generally accepted at the present time, as to pitch at least, is that as when a tone is sung over the strings of a piano, certain strings are set in vibration sympathetically, so in the basilar membrane, where, as in the piano, there are fibers of different lengths, these respond to different tones, and that in connection with each tone there is a separate filament of the auditory nerve, so that if the note is a high one a certain fiber is set in vibration, and the nerve-filament in communication with it transmits an impulse to certain cells in the brain, which when excited give the impression of a high note, and so with other notes and other nerve-cells.

*The Telephone Theory.*—The introduction of the telephone and a study of its mechanism have led some writers to question the explanation which is generally accepted of the mechanism of hearing, and to suggest that as the single telephone wire transmits the complex sounds produced by an orchestra to a distance where they are reproduced in all their variety of intensity, pitch, and quality, so “the cochlea does not act on the principle of sympathetic vibration, but that the hairs of all its auditory cells vibrate to every tone, just as the drum of the ear does; that there is no analysis of complex vibration in the cochlea or elsewhere in the peripheral mechanism of the ear; that the hair-cells transform sound-vibrations into nerve-vibrations similar in frequency and amplitude to the sound-vibrations; that simple and complex vibrations of nerve-molecules arrive in the sensory cells of the brain, and there produce, not sound again, of course, but the sensations of sound, the nature of which depends not upon the stimulation of different sensory cells, but on the frequency, the amplitude, and the form of the vibrations coming into the cells, probably through all the fibers of the auditory nerve.” This explanation has been put forth by Prof. William Rutherford under the title of the “Telephone Theory of the Sense of Hearing.”



In referring to this subject, Waller compares the basilar membrane to the membrana tympani in the following language: "It is the internal drum-head, repeating the complex vibrations of the membrana tympani, and vibrating in its entire area to all sounds—although more in some parts than in others—giving what we may designate as acoustic pressure patterns between the membrana tectoria and the subjacent field of hair-cells. In place of an analysis by sympathetic vibration of particular radial fibers, it may be imagined that varying combinations of sound give varying pressure patterns, comparable to the varying retinal images of external objects."

There are several terms used in the discussion of the subject of sound which it is important to understand; especially is this true for the medical student, for he will constantly meet them in his study of physical diagnosis.

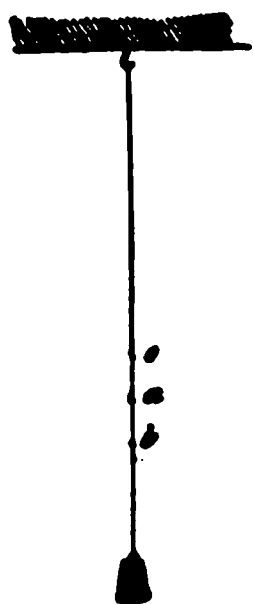


FIG. 398.—Weight and cord.

**Period; Amplitude; Frequency.**—If a weight attached to a rubber cord (Fig. 398) is pulled down and then released, the weight and the particles composing the cord will vibrate, and any particle, as *a*, will oscillate between two extreme points, as *b* and *c*, which are equidistant from *a*. The motion of *a* from *c* to *b* and back again to *c* is *one vibration* or *one complete vibration*, and the time this occupies is the *period* of the vibration.

The distance from *a*, when the particle is in equilibrium, to *b* or to *c* is the *amplitude* of the vibration, and the number of complete vibrations in one second is the *frequency*.

**Noises.**—These are sounds produced by *irregular* vibrations—*i. e.*, wanting in periodicity; or by *discordant* or *dissonant* sounds—*i. e.*, sounds which differ from one another in pitch; or they may be single, sudden sounds, as the report of a cannon. Noises are disagreeable sounds.

**Musical Sounds.**—These are sounds produced by *regular* vibrations, and they produce a pleasing effect upon the ear.

It should be said, however, that what may under some circumstances be a noise may, under others, produce the effect of a musical tone. Haughton says: "Nothing can be imagined more purely a noise or less musical than the jolt of the rim of a cab wheel against a projecting stone; yet if a regularly repeated succession of such jolts takes place, the result is a soft, deep, musical sound that will bear comparison with notes derived from more sentimental sources." And Zahm says: "With a sufficient number of properly tuned bottles a skilful performer could, by

merely withdrawing the corks, easily evoke a simple melody that every one would recognize."

Musical sounds differ in intensity, pitch, and quality.

**Intensity.**—This depends upon the energy with which the particles of air in vibration strike upon the ear, and: (1) Varies directly as the square of the amplitude of vibration of the sounding body; (2) varies inversely as the square of its distance; and (3) diminishes with the density of the air.

**Loudness** is oftentimes spoken of as synonymous with intensity, but it depends somewhat upon the condition of the ear and upon the rate of vibration, all sounds not affecting the ear alike, as well as upon the energy of vibration.

**Pitch.**—This depends upon the frequency of vibration or *vibration frequency*, as it is called; the more vibrations per second, the higher is the pitch. There must be at least 30 vibrations in a second to produce a continuous sound, and when these are more frequent than 38,000 in a second they become inaudible, at least to the human ear, although other creatures than man may still hear them. These limits are those assigned by Helmholtz; others give the lowest number as 16 and the highest as 41,000. Most musical sounds are produced by vibrations between 27 and 4000 a second.

**Quality.**—This is called also *timbre* and *tone-color*. As it is a property of sound which is difficult to understand, and even to define, we will quote some of the definitions which are given of it. Thus the *Standard Dictionary* defines "quality" as "That which distinguishes sounds of the same pitch and intensity from different sources, as from different instruments." And this same authority defines "timbre" as "The special peculiarity of a continuous sound or musical tone, or that common to all tones from the same source, as the human voice or some particular instrument, distinguishing them from notes from different sources, due to the special form of the sound-waves; the quality of a tone, as distinguished from *intensity* and *pitch*, called sometimes *tone-color*." This sentence is quoted by the *Standard* from Silliman's *Physics*: "The essential difference between the bass and tenor voices, and between the contralto and soprano, consists in the tone or *timbre* which distinguishes them even when they are singing the same note."

Quality is, then, concisely, that which enables us to distinguish one sonorous body from another—as, a piano from a violin, or a flute from a harp, etc.; and Helmholtz has demonstrated that "*the quality of a sound is determined by the number, order, and relative intensity of the partial tones into which it can be decomposed.*" To understand this it will be necessary to consider briefly the compound character of musical sounds.

**Compound, Fundamental, and Partial Tones.**—When a string

stretched between two points is set in vibration, as by drawing the bow of a violin over it, it will vibrate as a whole (Fig. 399, *a-b*) and emit a tone which, being the lowest that it can emit, is its *fundamental* or *prime* tone. If now this string is held at its middle point, *c*, and either half is bowed, that half of the string will vibrate, and after the finger has been removed the other half will also vibrate, and the tone emitted will be an octave higher; in a similar manner the string may be held at one-third, one-fourth, etc., of its length, and the string when bowed will divide

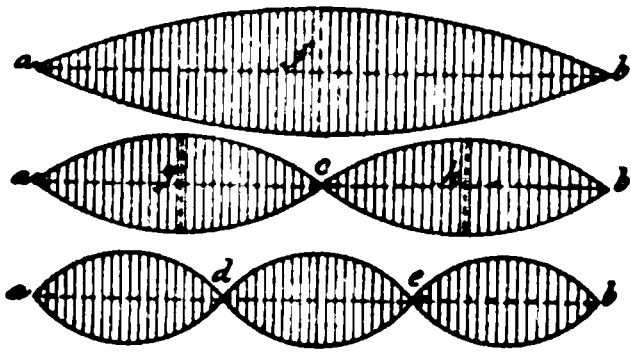


FIG. 399.—Vibrating strings.

into three or four segments, and the frequency of the emitted tones will be three or four times that emitted by the string when it vibrated as a whole. Such a series of tones is a *harmonic series*, and all the tones above the fundamental are *harmonic overtones*, or *upper partial tones*, or simply *partial tones*. To demonstrate this more effectively, a *sonometer* may be used, which con-

sists of a wire stretched over a sounding-box (Fig. 400) with a graduated scale, so that the divisions of the wire may be accurately determined. In order to produce these overtones it is not necessary to divide the string with the finger, or, in the case of the sonometer, the wire with the bridge; for in the vibration of the string or wire as a whole it divides itself, so that it may vibrate as a whole and also in segments; and consequently, while the whole vibrating string or wire emits the fundamental tone, the subdivided segments emit each its own partial tone, producing therefore *compound tones*, the fundamental tone determining the pitch. As a rule, the

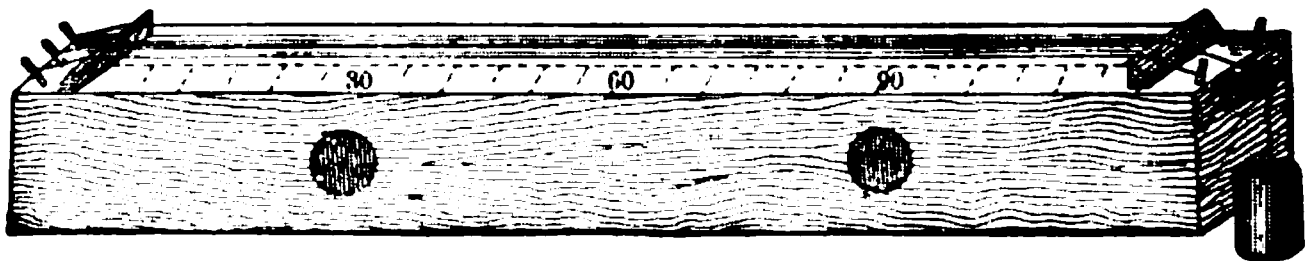


FIG. 400.—Sonometer.

sounds of musical instruments are *compound tones*, and, as Helmholtz has shown, it is the partial tones which determine their quality by which they are differentiated from one another, there being no difference in the fundamental tones. Thus if a key on a piano, say "middle *C*," is struck, the string will vibrate as a whole 132 times in a second, producing one fundamental tone, *C*, and it will also break up into segments which will vibrate respectively 264 times, producing the octave *C'*; 396 times, producing the fifth above this; 528 times, producing the second octave *C''*; 660 times, producing the third above this, etc.

These tones are believed to form a composite wave, and as such to strike the *membrana tympani*; and, according to the “piano theory,” this wave is analyzed into its component tones by the basilar membrane, each of whose fibers is caused to vibrate by a partial tone; while according to the “telephone theory” this analysis takes place in the brain.

*Resonators*.—That musical sounds possess this compound character Helmholtz demonstrated by means of *resonators* (Fig. 401), which consist of metallic globes of various sizes having two openings of unequal diameter. If one of these is held with its small opening to the ear, and the large one is held toward a source of sound, the resonator will resound when a tone is emitted which corresponds to the vibration-rate of its contained air, and to no other, and by using a series of these the various overtones may be identified.

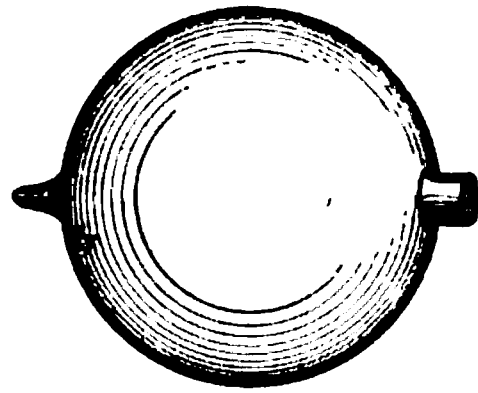


FIG. 401.—Resonator.

To sum up the properties of sounds and their causes, we may say that the *amplitude* of a wave determines its *intensity*; its *vibration-frequency*, its *pitch*; its *form*, its *quality*.

*Semicircular Canals, Utricle, and Saccule*.—The utricle and saccule have been regarded by some authorities as having the function of responding to irregular vibrations, and as being connected, therefore, with the perception of *noises*, while the perception of musical sounds depends upon the cochlea; but the consensus of opinion now is that, together with the semicircular canals, they are connected with the important function of the preservation of the equilibrium of the body, the *utricle* and *saccule* with *static* equilibrium—*i. e.*, when the body is in a state of rest; the *semicircular canals* with *dynamic* equilibrium—*i. e.*, when the body is in motion. This subject is discussed in connection with the cerebellum (p. 493).

## V. REPRODUCTIVE FUNCTIONS.

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THE reproductive functions are those concerned in the perpetuation of the species. In the lower forms of animal life, where the individual consists of a single cell, this process of reproduction is very simple, consisting of the division of the cell into two, each of which has the power of dividing to form new individuals in the same manner as it was formed. This is *asexual* reproduction. In the higher animals the reproduction is *sexual*—that is, it requires the union of two elements produced in the organs of two individuals, the male and the female, neither of which can accomplish the process alone.

### REPRODUCTIVE ORGANS.

These organs, which are also called the genital or generative organs, are in the male the testes, each with its duct, the vas

FIG. 402.—Diagram representing the male genital apparatus of right side: *A*, bladder; *B*, prostatic urethra; *C*, membranous urethra; *D*, spongy urethra. 1, Right testicle; 2, epididymis; 3, vas deferens, with 3', its ampulla; 4, seminal vesicle; 5, ejaculatory duct opening at the verumontanum; 6, Cowper's gland; 7, its excretory duct (Testut).

deferens, the vesiculæ seminales, and the penis (Fig. 402); and in the female, the ovaries, Fallopian tubes, uterus, and vagina.

**Genital Organs of the Male.—Testes.**—The testes or testicles (Fig. 403), two in number, are situated in the scrotum. They are composed of *lobules*, the number of which in each testis is variously estimated at from two hundred and fifty to four hundred. In each lobule are convoluted seminiferous tubules, *tubuli seminiferi*, varying in number from one to three.

These tubules contain epithelial cells of two varieties, *sustentacular cells*, or *Sartoli's columns*, and *spermatogenic cells*, the latter being related only to the formation of spermatozoa. These two varieties of cells are sometimes described as the parietal cells. Internal to these are the *mother-cells*, which are derived from the spermatogenic cells by the process of mitosis or karyokinesis

*Globus Major*

*Efferentia*

FIG. 403.—Vertical section of the testicle to show the arrangement of the ducts (Leroy).

(p. 28). These give rise to a third and more internal layer of *daughter-cells*, from whose nuclei, by the disappearance of the cell-body, the *spermatoblasts* are developed. These in turn become *spermatozoa*. This process by which spermatozoa are formed is known as *spermatogenesis*.

**Spermatozoa** (Fig. 404).—A human spermatozoon is about  $50\ \mu$  in length, and consists of a head from  $3\ \mu$  to  $5\ \mu$  long, a body and a tail, the last terminating in the end-piece of Retzius, which is the end of the axial fiber which runs through the center of the body and tail. The tail during the living condition is in rapid motion, by virtue of which the spermatozoon can travel quite rapidly. The vitality of spermatozoa is considerable, as they can live for several

days outside the body, and they are also very resistant to low temperatures. They appear at the time of puberty, and have been found in individuals ninety years of age, though they are not com-



FIG. 404.—Human spermatozoa. The two at the left after Retzius; the one at the extreme left is seen in profile; the others in surface view; the one at the right is drawn as described by Jensen: a, head; b, terminal nodule; c, middle piece; d, tail; e, end-piece of Retzius (Böhm and Davidoff).

temperatures. They appear at the time of puberty, and have been found in individuals ninety years of age, though they are not com-

FIG. 405.—Spermatozoa: a, human; b, of the rat; c, of menobranchus ( $\times 460$ ).

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FIG. 406.—Cross-section of vas deferens near the epididymis (human) (Huber).

monly found in semen after the age of seventy or seventy-five years is past. The spermatozoa of different animals vary in size, though their general appearance is much the same (Fig. 405).

Their number is very great; some writers state that in a single ejaculation as many as 25,000,000 may be discharged, while one has placed their number as high as 412,500,000. Both figures may be correct, inasmuch as the amount of semen ejaculated varies at each emission.

The seminiferous tubules terminate at the apices of the lobules



FIG. 407.—Vas deferens and seminal vesicle, *A*, seen in longitudinal and, *B*, in horizontal section: 1, vas deferens; 2, its terminal or ampullary portion; 3, seminal vesicle with, 3', its partitions; 4, its terminal portion; 5, ejaculatory duct (Testut).

FIG. 408.—Right seminal vesicle, unfolded and seen on its posterior aspect (subject of forty years, previous injection of tallow): 1, vas deferens, with, 1', its ampulla; 2, seminal vesicle with, 3, its lateral prolongation; 4, its enlargements in form of cecum; 5, protuberances of its wall; 6, junction of the vesicle and vas deferens; 7, ejaculatory duct (the dotted line, *x x*, indicates the level of the upper extremity of the vesicle before its unfolding) (Testut).

in the vasa recta (straight tubes), about thirty in number. In the mediastinum these tubes form a network, the rete testis, the vessels of which end in the vasa efferentia, about fifteen in number. These vessels connect the testicles with the epididymis, the continuation of which is the vas deferens. The canals of the rete testis are lined by non-ciliated epithelium; the *vas aberrans*, how-



ever, which is connected with it, has ciliated epithelium. Ciliated columnar and non-ciliated cubical epithelium line the vasa efferentia.

*Vas Deferens* (Fig. 406).—This duct, the excretory duct of the

FIG. 409.—Sagittal section through the ampulla of the right vas deferens and ejaculatory duct: 1, ampulla of vas deferens; 2, ejaculatory duct; 3, seminal vesicle dissected away in its middle portion; 4, its opening into the ejaculatory duct; 5, bladder; 6, urethra; 7, prostate; 8, verumontanum.

testis, has a thick muscular wall. Its lining epithelium is partly simple ciliated columnar, and partly stratified ciliated columnar,

FIG. 410.—Seminal vesicles and vasa deferentia, posterior view: 1, bladder; 2, prostate; 3, 3', seminal vesicles; 4, 4', vasa deferentia; 5, ejaculatory ducts; 6, 6', ureters; 7, 7', perivesicular cul-de-sac of peritoneum; 8, interdeferential triangle, in direct relation with the rectum, from which it is separated only by the prostate-peritoneal aponeurosis. The two crosses (+ +) indicate the points at which the ureters disappear in the vesical wall (Testut).

though the cilia are sometimes absent. At the base of the bladder this duct lies between it and the rectum, and here presents an

enlargement, the *ampulla* (Figs. 407, 408), beyond which, at the base of the prostate, it narrows and joins with the duct of the *vesicula seminalis*, thus forming the ejaculatory duct (Fig. 409). The total length of the duct is about 60 cm.

*Vesicula Seminalis* (Fig. 410).—This structure is a diverticulum from the vas deferens, and glands exist in its mucous membrane which is covered with non-ciliated columnar epithelium. Some authorities regard it as a storehouse for the semen, while others do not regard this as one of its functions. Böhm and Davidoff state that "spermatozoa are, as a rule, not met with in the seminal

FIG. 411.—Section of penis, bladder, etc.: 1, symphysis pubis; 2, prevesical space; 3, abdominal wall; 4, bladder; 5, urachus; 6, seminal vesicle and vas deferens; 7, prostate; 8, plexus of Santorini; 9, sphincter vesicæ; 10, suspensory ligament of penis; 11, penis in flaccid condition; 12, penis in state of erection; 13, glans penis; 14, bulb of urethra; 15, cul-de-sac of bulb. a, Prostatic urethra; b, membranous urethra; c, spongy urethra (Testut).

vesicles." The vas deferens and especially its ampulla serve to retain the semen until ejaculated. A considerable amount of fluid is added to the semen by the secretion of the mucous membrane lining the *vesicula seminalis*, and this is probably its most important function. The ejaculatory ducts discharge into the urethra at its prostatic part.

The prostate gland and Cowper's glands contribute also to the formation of the semen.

*Semen*.—The semen or seminal fluid consists of secretions from

the testes, vasa deferentia, vesiculæ seminales, prostate, Cowper's glands, and the muciparous glands of the urethra. It is whitish in color, viscid in consistency, alkaline in reaction, and possesses a characteristic odor. The amount ejaculated varies from 0.5 c.c. to 6 c.c. It contains from 82 to 90 per cent. of water, nuclein, protamin, proteids, xanthin, lecithin, cholesterin, fat, sodium and potassium chlorids, sulphates, and phosphates. From it may be obtained Charcot's crystals, which are a phosphate of the nitrogenous base, spermin, and which have

their origin in the portion of the semen which is contributed by the prostate; to the decomposition of the substance which produces these crystals the odor of the semen is attributable. While the spermatozoa are the essential fertilizing agents, the presence of the fluid portion of the semen is important as giving to them their mobility, without which they could not travel in the generative passages.

**Penis** (Fig. 411).—The penis serves a double purpose, inasmuch as it is the organ of copulation and also the termination of the urinary passages. The former function is undoubtedly the essential one, for there is no reason why the urinary passages could not terminate at the surface of the body; it is, however, manifestly advantageous in providing for the perpetuation of the species that the semen should be expelled as near as possible to the mouth of the uterus, a result which is obtained by the intromission of the penis.

FIG. 412.—Sagittal section of the anterior extremity of the penis: 1, glans penis; 2, corpus cavernosum; 3, 3, spongy portion of urethra; 4, meatus urinarius; 5, fossa navicularis; 6, left half of the valve of Guérin; 7, sinus of Guérin between the valve and the anterior wall of the urethra; 8, left lateral border of urethra; 9, its lower surface; 10, prepuce pushed back behind the glans; 11, frenum; 12, integument; 13, dorsal vein; 14, fibrous partition between the corpus cavernosum and corpus spongiosum (Testut).

The penis consists of erectile tissue arranged in three subdivisions,

two above, *corpora cavernosa*, and one below, *corpus spongiosum*, which latter terminates in the *glans penis*. The *corpora cavernosa* are surrounded by fibro-elastic sheaths from which are given off *trabeculae*. These pass inward, and between them are spaces which contain venous blood. A similar structure characterizes the *corpus spongiosum* which encloses the urethra.

The arteries which supply the penis are derived from the internal pudic (Fig. 413). Sensory nerves are distributed to the

skin of the penis, and especially to the glans penis, where they terminate in Meissner's corpuscles, Krause's spheric end-bulbs, and genital corpuscles (Fig. 414).

FIG. 413.—Diagram of the arterial circulation of the penis: 1, corpus cavernosum, with 1', its root; 2, suspensory ligament; 3, corpus spongiosum with 4, bulb; 5, glans; 6, internal pudic artery; 7, bulbo-urethral artery, with 7', its bulbar branch, 7'', its anterior branch going to the frenum; 8, arteria cavernosa, with 8', its recurrent branch; 9, dorsal artery; 10, 10, its lateral branches; 11, its termination in the glans (Testut).

Sensory nerves are distributed also to the *verumontanum*, in the urethra, and the pleasurable sensations connected with coitus are due to the excitation of the nerves here distributed, as well as to those supplying the glans penis.

In addition to sensory nerves there are also distributed to the penis excitator nerves, *nervi erigentes*, which are derived from the first and second, and sometimes from the third, sacral nerves; they are vasodilator nerves, and have their origin in the sexual center of the spinal cord.

**Genital Organs of the Female.—Ovary.**—The ovaries (Fig. 415), two in number, are attached to the posterior surface of the broad ligament, one on each side of the uterus, with which they are connected by the *ovarian ligament*, a fibromuscular structure. They are covered by peritoneum, except at the hilum, which is, however, somewhat modified, its mesothelial cells forming the *germinal epithelium* (Fig. 416), the cells of which are

FIG. 414.—Genital corpuscle from the glans penis of man; methylene-blue stain (Dogiel, *Arch. f. mik. Anat.*, vol. xli.).

**FIG. 415.**—Posterior view of left uterine appendages: 1, uterus; 2, Fallopian tubes; 3, fimbriated extremity and opening of the Fallopian tube; 4, parovarium; 5, ovary; 6, broad ligament; 7, ovarian ligament; infundibulopelvic ligament (Henle).

**FIG. 416.**—Section through part of ovary of adult bitch: *a*, germinal epithelium; *b, b*, ingrowths (egg-tubes) from the germinal epithelium, seen in cross-section; *c, c*, young Graafian follicles in the cortical layer; *d*, a more mature follicle, containing two ova (this is rare); *e* and *f*, ova surrounded by cells of diacus proligerus; *g, h*, outer and inner capsules of the follicle; *i*, membrana granulosa; *l*, blood-vessels; *m, m*, parovarium; *o*, germinal epithelium commencing to grow in and form an egg-tube, *x*, transition from peritoneal to germinal epithelium (from Waldeyer).

cubical or cylindrical and higher than those of the rest of the peritoneum. At the hilum the connective tissue of the ovarian ligament passes into the ovary, forming the *stroma* (Fig. 417), which constitutes the greater part of the organ. The spindle-shaped cells of the stroma are regarded by His as unstriped muscle-cells, while Waldeyer, Henle, and others consider them to be connective-tissue cells. Beneath the germinal epithelium is a condensed portion of the stroma, which was formerly described under the name of *tunica albuginea*, and was regarded as a covering or coat of the ovary. The outer third of the ovary is the *cortex*, while the inner or deeper two-thirds is the *medulla*, in

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FIG. 417.—Part of the same section as represented in Fig. 415, more highly enlarged: 1, small Graafian follicles near the surface; 2, fibrous stroma; 3, 3', less fibrous, more superficial stroma; 4, blood-vessels; 5, a follicle still further advanced; 6, one or two more deeply placed; 7, one further developed, enclosed by a prolongation of the fibrous stroma; 8, part of the largest follicle; *a*, membrana granulosa; *b*, discus proligerus; *c*, ovum; *d*, germinal vesicle; *e*, germinal spot (Schrön).

which are the blood-vessels giving to this medullary portion another name by which it is sometimes known, *zona vasculosa*. In the cortex above are the *Graafian follicles*, the medulla containing none of them. These are sacs varying in size according to the stage of their development. In the Graafian follicles are the ova, the least developed of which are covered by a single layer of cells, those further advanced, by several layers, constituting the *membrana granulosa*. The ova and the cells are derived from the germinal epithelium.

A mature Graafian follicle (Fig. 418) has a diameter of from 8 to 19 mm., and extends from the medulla to the surface of the ovary and projects therefrom (Fig. 419), rupturing at the most

projecting part and permitting the escape of the ovum. The wall of the follicle, *theca folliculi*, is a condensed layer of the stroma,



FIG. 418.—Section of fully developed Graafian follicle from injected ovary of pig;  $\times 50$  (Böhm and Davidoff).

and is itself divisible into an outer layer of fibrous connective tissue, *tunica externa*, and an inner, *tunica interna*, which is characterized by the presence of blood-vessels and of cells. Within the theca is the *membrana granulosa* or *stratum granulosum*, which is composed of several layers of small polyhedral cells. In one portion of the *membrana granulosa* the cells are very numerous, constituting the *discus proligerus*, in which the ovum lies embedded.

FIG. 419.—Ovary with mature Graafian follicle about ready to burst (Ribemont-Dessaignes).

The cells of the *discus proligerus* which are in contact with the ovum are arranged radially, constituting the *corona radiata* (Fig. 422). Between the *discus proligerus* and the *membrana granulosa*, except at the point where the two are in contact, is a cavity, the *antrum*, which is filled with

a fluid, *liquor folliculi*, formed by a secretion of the cells and by the destruction of some of them.

Graafian follicles continue to be formed in the ovary for a short time after birth, and have been estimated to number, in both ovaries, more than 70,000; but a small proportion of these, however, become mature, the rest undergoing degeneration.

During the development of Graafian follicles the ova which they contain also become developed in the following manner (Nagel, Böhm and Davidoff). In the early period of the development of the ovary the germinal epithelium pushes into the subjacent connective tissue in solid projections (Fig. 416); these form the *primary egg-tubes of Pflüger*, some of the cells of which become ova, while others become Graafian follicles. The differentiation

FIG. 420.—Mature ovum of rabbit: a, cells from the discus proligerus (epithelium of ovum); b, zona pellucida; c, vitellus; d, germinal vesicle; e, germinal spot; f, large globules with dull luster in the germinal vesicle.

of the cells of the germinal epithelium into ova and follicles may occur in the epithelium itself, in which case the larger cells constitute *primitive* or *primordial ova*. "In the further development of the ovarian cortex the primitive egg-tubes are penetrated throughout by connective tissue, so that each egg-tube is separated into a number of irregular divisions. In this way a number of distinct epithelial nests are formed, which lose their continuity with the germinal epithelium and finally lie embedded in the connective tissue. According to the shape and other characteristics of these epithelial nests, we may distinguish several different groups: (1) The primitive egg-tubes of Pflüger; (2) the typical primitive follicles—i. e., those which contain only a single egg-cell (present in the twenty-eighth week of fetal life); (3) the atypical follicles—i. e.,



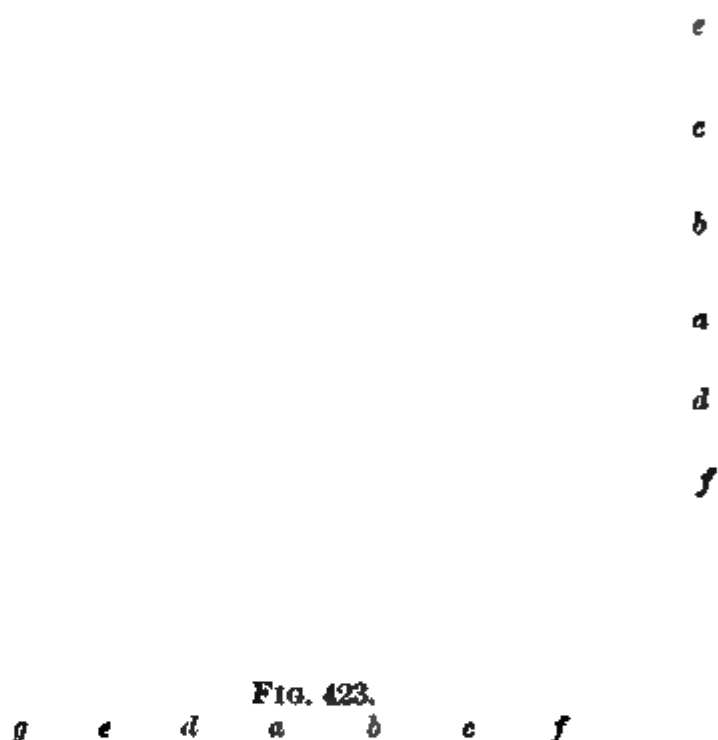
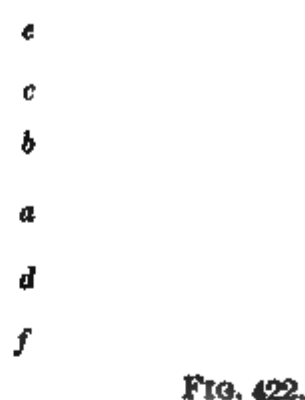


FIG. 424.

FIGS. 421-424.—From sections of cat's ovary, showing ova and follicles in different stages of development: *a*, *a*, *a*, *a*, germinal spots; *b*, *b*, *b*, *b*, germinal vesicles; *c*, *c*, *c*, *c*, ova; *d*, *d*, *d*, zona pellucida; *e*, *e*, *e*, *e*, corona radiata; *f*, *f*, *f*, *f*, theca folliculorum; *g*, beginning of formation of the cavity of the follicle;  $\times 225$  (Böhm and Davidoff).

those containing two or three egg-cells; (4) the so-called nests of follicles, in which a large number of follicles possess only a single connective-tissue envelope; (5) follicles of the last-named type, which may assume the form of an elongated tube, and which are then known as the constricted tubes of Pflüger. The fourth, fifth, and possibly the third types are further divided by connective-tissue septa, until they finally form distinct and typical follicles (Schottländer).

"In the adult ovary true egg-tubes are no longer developed. Isolated invaginations of the germinal epithelium sometimes occur, but apparently lead merely to the formation of epithelial cysts (Schottländer). The theories as to when the formation of new epithelial nests or follicles ceases are, however, very conflicting, some authors believing that cessation takes place at birth, others that it continues into childhood and even into middle age.

"The ova of the primitive or primordial follicles attain a size (in fresh tissue teased in normal salt solution) varying from  $48\ \mu$  to  $69\ \mu$ . They possess a nucleus varying in size from  $20\ \mu$  to  $32\ \mu$ , presenting a doubly contoured nuclear membrane, and containing a distinct chromatin network with a nucleolus and several accessory nucleoli. The protoplasm shows a distinct spongioplastic network containing a clear hyaloplasm. The primitive ova, until they undergo development, retain this size and structure, irrespective of the age of the individual. They are numerous in embryonic life and early childhood, always found during the ovulation period, but not observed in the ovaries of the aged. Changes in the size and structure of the ova accompany the proliferation of the follicular cells in the growing follicles. As soon as the follicular cells of a primitive follicle proliferate, as above described, the ovum of the follicle increases in size until it has attained the size of a fully developed ovum. The zona pellucida now makes its appearance, and after this has reached a certain thickness, yolk granules (deutoplastic granules) develop in the protoplasm of the ovum. In a fully developed Graafian follicle the ovum presents an outer clearer protoplasmic zone and an inner fine granular zone containing yolk-granules; in the former lies the germinal vesicle. Between the protoplasm of the ovum and the zona pellucida is found a narrow space known as the perivitelline space. The germinal vesicle (nucleus), which is usually of spherical shape, possesses a doubly contoured membrane and a large germinal spot (nucleolus), which shows ameboid movements.

"The origin of the zona pellucida has not as yet been fully determined. It probably represents a product of the egg-epithelium, and may be regarded in general as a cuticular formation of these cells. At all events it contains numerous small canals or pores into which the processes of the cells composing the corona

radiata extend. These processes are to be regarded as intercellular bridges (Retzius); and, according to Palladino, they occur not only between the ovum and the corona radiata, but also between the follicular cells themselves. In the ripe human ovum the pores are apparently absent (Nagel), and it is very probable that they have to do with the passage of nourishment to the growing egg. Retzius believes that the zona pellucida is derived from the processes of the cells composing the corona radiata, which at first interlace and form a network around the ovum. Later, the matrix of the membrane is deposited in the meshes of the network, very probably by the egg itself."

*Ovum*.—The human ovum has a diameter of from 0.22 to 0.32 mm. The external envelope is the *zona pellucida*, the origin of which, as has been stated, is uncertain. Within this is the *vitellus* with its nucleus, the *germinal vesicle*, whose diameter is from 30  $\mu$  to 40  $\mu$ . The vitellus consists of a protoplasmic network, in the

FIG. 425.—Portion of broad ligament stretched to show the parovarium (P) lying between the folds and consisting of the head-tube and cross-tubules (Gegenbaur).

meshes of which are embedded highly refractive oval bodies, the yolk-globules.

The germinal vesicle has a distinct enveloping membrane, and within it is a scanty framework with a small amount of chromatin, and one or two false nucleoli, *germinal spots*, due to the thickening of the chromatin. These structures have a diameter of from 7  $\mu$  to 10  $\mu$ .

*Paroovarium* (Fig. 425).—This structure is known also as the *epoöphoron* and the *organ of Rosenmüller*. It lies within the broad ligament, between the Fallopian tube and the ovary, and represents what remains of the Wolffian body of the fetus. The tubules of that organ being the short canals of the paroovarium, and the upper part of the Wolffian duct being represented by the head-tube. This latter sometimes persists as a patent canal, constituting *Gärtner's duct*, which is the homologue of the *vas deferens*. The *paroöphoron* is a structure sometimes observed

within the broad ligament near the ovary, ordinarily closer to the uterus than the parovarium. It appears also as tubules, and these

**FIG. 426.**—Dissection of the pelvic organs, showing the relation of the abdominal parietes to the round ligaments and the bladder: 1, 3, the obliterated hypogastric arteries; the urachus (Bourgery and Jacob).

correspond to the transverse tubules of the lowest part of the fetal Wolffian body. The tubules in adult life sometimes be-

**FIG. 427.**—Fallopian tube laid open; *a, b*, uterine portion of tube; *c, d*, folds of mucous membrane; *e*, tubo-ovarian ligament or fimbria ovarica; *f*, ovary; *g*, round ligament (from Playfair).

come distended, forming cysts which require operative interference for their removal.

**Fallopian Tubes** (Figs. 427, 428).—These tubes are each about 10 cm. in length, and extend from the angles of the uterus to the vicinity of the ovaries. The ovarian extremity of each tube expands into a funnel-shaped opening, the *pavilion* or *infundibulum*, which is surrounded by fringed processes, the *fimbriae*. At the uterine extremity its lumen will scarcely admit a bristle, while at the *ostium abdominale*, the outer opening where the tube expands into the infundibulum, its diameter is about 4 mm.

The tube is composed of three coats, an internal mucous, next to this a muscular, and, most external, a serous or peritoneal. The

FIG. 428.—Transverse section of Fallopian tube, showing the complicated arrangement of the longitudinal plications which are here cut across (Martin).

mucous membrane is arranged in longitudinal folds (Figs. 427, 428) and covered by a single layer of ciliated columnar epithelium. There are no distinct glands in the duct, though some writers regard the crypts as fulfilling the function of glands. The muscular coat consists of an inner circular and an outer longitudinal layer.

**Uterus** (Fig. 429).—This organ in the virgin condition has a length of about 7.5 cm., a width of 4 cm. at its widest part, and a thickness of 2.5 cm. It is divided into a body or corpus and a neck or cervix, and is composed of three coats—mucous, muscular, and peritoneal. The *mucous*, which is the internal coat, is covered

by a single layer of columnar ciliated epithelium, that extends to the external os, where the epithelium is of the stratified

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FIG. 429.—Anterior view of virgin uterus, showing relations of cervix to corpus uteri and reflection of peritoneum at isthmus.

squamous variety. Some authorities describe this latter variety of epithelium as covering the lower third of the cervical mucous

FIG. 430.—Section of human uterus, including mucosa (a) and adjacent muscular tissue (b); c, epithelium of free surface and tubular uterine glands (d); f, deepest layer of mucosa, containing fundi of glands; h, strands of non-striped muscle penetrating within the mucosa (Piersol).

membrane. In the mucous membrane are numerous *uterine glands* (Fig. 430), into which the ciliated epithelium extends. The

motion of the cilia of the uterine mucous membrane is toward the vagina. In the mucous membrane of the cervix are closed sacs lined by cylindrical or ciliated epithelium; these are the *ovula Nabothi*, and are regarded as cystic formations.

The *muscular* coat (Fig. 431) consists of three layers: An inner and an outer, both longitudinal; and a middle circular, which is more highly developed than the other two. The muscular tissue is of the unstriped variety (Fig. 432).

**Ovulation.**—The formation of ova in the human female is

FIG. 431.—Arrangement of uterine muscle, as seen from in front after removal of serous coat (Hélle).

probably complete two years after birth. Although during this period, and, indeed, even before birth, some ova may undergo development to some extent, still it is not until the period of puberty that there is any approach to regularity in the development of either the Graafian follicles or the ova. At undetermined periods Graafian follicles rupture and mature ova are discharged, together with the cells of the *discus proligerus*. This ripening and discharge of ova constitute ovulation. The cause of the

rupture of the follicle is still an unsettled question. In discussing this subject Böhm and Davidoff say:

"The manner in which the fully developed Graafian follicle bursts and its ovum is freed is still a subject of controversy; the following may be said regarding it: By a softening of the cells forming the pedicle of the discus proligerus, the latter, together with the ovum, are separated from the remaining granulosa, and lie free in the liquor folliculi. At the point where the follicle comes in contact with the tunica albuginea of the ovary the latter, with the theca folliculi, becomes thin, and in this region, known as the stigma, the blood-vessels are obliterated and the entire tissue gradually atrophies; thus a point of least resistance is

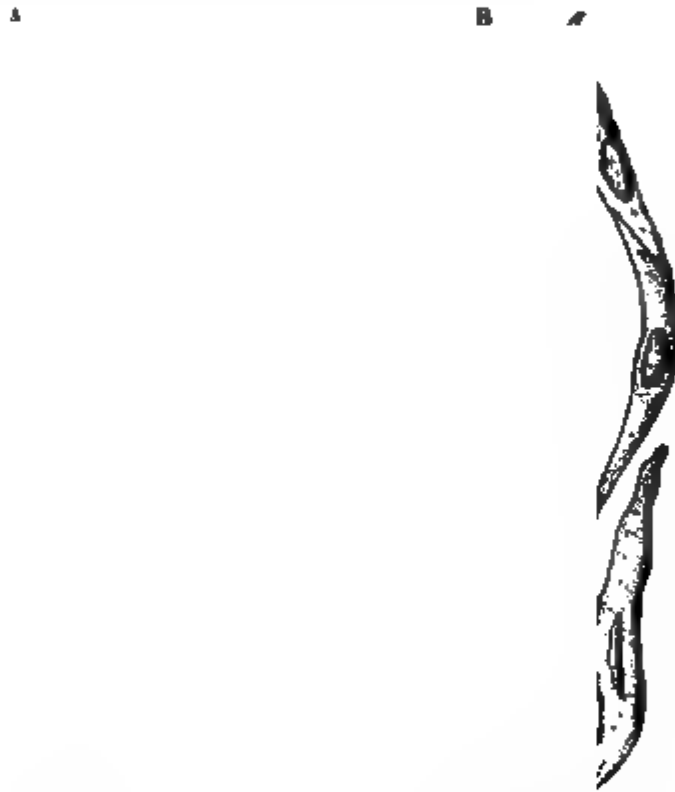


FIG. 432.—A, isolated muscle-elements of the non-pregnant uterus; B, cells from the organ shortly after delivery (Sappey).

formed which gives way at the slightest increase in pressure within the follicle, or in its neighborhood.

"The increase of pressure within the follicle, leading to its rupture, is, according to Nagel, due to a thickening of the tunica interna of the theca of the follicle. The cells of this layer proliferate and increase in size and show yellowish colored granules. This cell-proliferation leads to a folding of the tunica interna, the folds encroaching on the cavity of the follicle, and causing its contents to be pushed toward the stigma."

Piersol states that the liberation of the ova usually takes place at definite times, which in general coincide with the menstrual epochs, one or more ova being set free at each period. This



coincidence, however, is by no means necessary or invariable, since ovulation undoubtedly proceeds independently of menstruation. Other authorities regard the intervals between periods of ovulation as very irregular. J. Bland Sutton, in his *Surgical Diseases of the Ovaries and Fallopian Tubes*, says: "In the ovary of the human fetus ova ripen, form follicles, and undergo suppression during the last month of intra-uterine life. The life of the human ovary may be divided into the following periods of activity and repose: The first period extends from the seventh month of intra-uterine life to the end of the first year. Ova ripen in such abundance that in some cases a marked diminution in the number of the ova is appreciable at the second year after birth. To this succeeds a period of comparative repose, terminating at the tenth or twelfth year; then the ripening of the ova is again easily detected, and goes on independently of menstruation, even after the accession of the climacteric."

In an uncertain proportion of instances the ova find their way into the Fallopian tube. The mechanism by which this is accomplished is still a matter of doubt. One theory maintains that the fimbriated extremity is so approximated to the ovary as to bring the ostium abdominale against the part at which the Graafian vesicle is about to rupture, and that the escaping ovum thus enters the tube. This approximation is by some writers supposed to be due to an engorgement of the fimbriated extremity by blood, thus causing its erection and approximation, but the absence of erectile tissue disproves this theory. Tait found, in certain cases upon which he operated, the tube grasping the ovary, and he attributed this action to muscular fibers in the tube which develop at the period of puberty and which atrophy at the menopause, so that ova can enter the tube only during the active life of these fibers, and then, and then only, can pregnancy take place, though both before puberty and after the menopause ovulation may occur, the ova under these circumstances falling into the abdominal cavity, where they disintegrate. According to this theory, if ovulation takes place and the tube does not grasp the ovary, the ovum when discharged does not enter the tube, but falls into the abdominal cavity.

The second theory is that this grasping of the ovary by the tube does not occur, but that the ovum is carried into the ostium abdominale by the current created by the ciliated epithelium lining the fimbriæ.

This latter theory is the one generally accepted at the present time. Indeed, facts are accumulating to show that this current is sufficiently powerful to carry an ovum from one ovary to the tube of the opposite side. Kelly removed a diseased left ovary and right tube from a woman who, fifteen months later, was delivered of a child at term. In this instance the ovum must have come from the right ovary and been carried to the uterus through the

left tube. This passage of an ovum from one ovary to the tube of the opposite side is *external migration*, and is perhaps not as infrequent as would at first be thought. *Internal migration* is the passing of an ovum from an ovary down the tube of the same side, through the uterine cavity, and to a greater or less extent up the tube of the opposite side. Internal migration is supposed to account for some tubal pregnancies. It is doubtful if it ever occurs. It is to be remembered that the ovum is but 0.25 mm. in diameter, and there seems no reason to question the power of the current to draw so small a body into the tube. Once in the tube, it is carried on to the uterus by the ciliated epithelium.

**Menstruation.**—At about the age of fourteen years a bloody discharge takes place from the vagina at intervals of about four weeks. This is the *menses*, and the process is *menstruation*. It should be noted that the period of life at which menstruation appears is by no means uniform in all individuals.

Byron Robinson, in the *Medical Brief*, says that “the influences which change the individual age of beginning are: Climate, race, residence, altitude, latitude and longitude, environments, food, and disease. Climate (atmospheric and geographical relations) exercises the chief influence among the various factors. In general, the hotter the climate the earlier the menstruation begins. The average age for the beginning of menstruation is: Chicago, fourteen; Sweden, eighteen; Norway, sixteen and one-half; Denmark, sixteen and three-fourths; Russia, fourteen; Germany, fifteen; Great Britain, fifteen; Austria, sixteen; Palestine, thirteen; Turkey, eleven; Syria, twelve; Ceylon, Siam, and Japan, thirteen.”

Prof. Skene, in his *Diseases of Women*, lays down the following rules:

1. Menstruation should begin at puberty—that is, when the woman is maturely developed, no matter what the age may be.

2. It should recur at regular intervals: about every twenty-eight days is the average time. A regular periodicity is normal, but the duration of the periods often differs in different persons.

3. The discharge should always be fluid in consistence and sanguineous in color.

4. The flow should continue a definite length of time, the duration depending upon the habit of each case; at least there should not be any great deviation from this rule. The duration is usually from three to five days, and the total amount is about four or five ounces.

At about the age of forty-five years menstruation ceases: this is the *menopause*, or climacteric, or change of life. The cessation is not abrupt, but gradual. The menstruation becomes irregular, and finally ceases altogether.

The changes which take place in the mucous membrane of

the body of the uterus during menstruation are not agreed upon by authorities.

Webster says that "the latest evidence points clearly to the view that there is but a slight denudation, irregular in distribution in the superficial layers of the mucosa."

The complete menstrual cycle is, according to Marshall, as quoted by the *American Text-book of Obstetrics*, divisible into four stages: (1) The first or *constructive stage* is one of preparation for the reception of an ovum, and is characterized by the formation of a menstrual decidua, in the preparation of which swelling of the mucous membrane, enlargement of the uterine glands, and increase of the connective tissue, all take place. This stage probably lasts one week, and is followed, when pregnancy has not occurred, by degenerative changes.

(2) The second or *destructive stage* is marked by the destructive processes which give rise to the usual phenomena of the

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FIG. 433.—Uterus during menstruation, cut open to show the swelling of the whole organ, and particularly the mucous membrane: *A*, mucous membrane of cervix; *B*, *C*, mucous membrane of corpus, much thickened; *D*, muscular layer; *E*, uterine opening of tube; *F*, os internum (the mucous membrane tapers down to these openings) (Courty).

menstrual period, including the discharge of mucus, blood, and disintegrated uterine mucous membrane. Five days constitute the average duration of the menstrual flow, although its continuance may be extended or curtailed, owing to individual peculiarities.

(3) The third or *reparative stage* is one of repair, during which the deeper and unaffected parts of the uterine mucous membrane institute constructive processes, which within the short period of from three to four days result in the formation of a new mucosa.

(4) The fourth or *quiescent stage* includes the remaining twelve or fourteen days of the menstrual cycle, and represents the quiescent period preceding the initiative changes marking the beginning of the next period.

**Cause of Menstruation.**—The cause of menstruation is still undetermined.

Lawson Tait held that menstruation was dependent upon the oviducts, but that ovulation and menstruation were independent functions.

Johnstone believed that menstruation is regulated by a nerve which passes through the broad ligament.

Byron Robinson holds that menstruation is due to ganglia located in the walls of the uterus and oviducts, which he terms "automatic menstrual ganglia." He considers it to be independent of ovulation. He calls the ovary the chief central sexual organ of woman, and the uterus and oviducts appendages of the ovary.

According to this writer (*loc. cit.*) menstruation is due to a nervous mechanism termed automatic menstrual ganglia, located in the walls of the uterus and oviducts. Its utility is the secretion of fluid to float an egg into the uterus. Its design is reproduction.

"Among the lower animals menstruation and ovulation are concomitant, but as the scale of life ascends they become separate processes. Man and monkey are probably the only animals with a distinct rhythmical or periodical menstrual discharge independent of ovulation. This process in lower animals is called œstrus or 'rut.' Menstruation is limited to a certain period of life, seed-time and harvest, generally from the fifteenth to the forty-fifth year. It is due to automatic menstrual ganglia, small nerve-ganglia situated in the walls of the uterus and tubes. It is a manifestation of the nervous system. It must be remembered that a nerve-ganglion is a small brain; it receives sensation and sends out motion; it assimilates food, and is a trophic center; it reproduces itself, and controls secretion and vermicular action; it is a physiological center, and has all the elements of a brain. These little ganglia are situated along the uterus and oviducts passing through a monthly rhythm, rising and sinking between the extremes of functional activity and repose, and corresponding in these states to the menstrual congestion and intermenstrual quietude of the uterus and oviducts. The oviducts at the monthly periods assume peristaltic motion, a vermicular or tortuous action, so that an ovum may be carried to the uterus by their movements. It may be observed that when the ganglia along the oviducts are

in the slightest action, the oviducts become filled with fluid secreted from the blood, which is whipped in a stream toward the uterus by the cilia that always move in that direction. This oviductal fluid furnishes a canal in which the ovum can float to the uterus; for in a dry, contracted oviduct an egg could pass only with difficulty. The automatic menstrual ganglia are similar to the other visceral ganglia, such as the cardiac and those of the digestive tract, and the renal ganglia."

Christopher Martin states his views on the subject as follows:

Menstruation is a process directly controlled by a special nerve-center situated in the lumbar part of the spinal cord, and the changes in the uterine mucosa during the period are brought about by katabolic nerves, and during the interval by anabolic nerves. The menstrual impulses reach the uterus either through the pelvic splanchnic or the ovarian plexus, possibly through both. And, finally, removal of the uterine appendages arrests menstruation by severing the menstrual nerves.

**Relation between Ovulation and Menstruation.**—The relation between these two processes is as yet undetermined, although physiologists in the main hold that at the time of the discharge of an ovum from an ovary there is such a condition of the uterus as brings about its increased vascularity and the oozing from its vessels of the menstrual blood. They believe that at each menstruation there is discharge of an ovum. Other writers—and these are principally surgeons who have devoted much time to the study of diseases of women, and who have had large experience in operations for the removal of the ovaries—differ very materially from the physiologists. One of the number (A. Reeves Jackson, in an article entitled "Ovular Theory of Menstruation: Will it Stand?" in the *American Journal of Obstetrics*) says: "Menstruation may occur without accompanying ovulation; ovulation may occur without accompanying menstruation; and ovulation is the irregular but constant function of the ovaries, while menstruation is the regular rhythmical function of the uterus." Lawson Tait, the celebrated surgeon, says that "ovulation and menstruation are not only not concurrent, but ovulation is much less frequent than menstruation." J. Bland Sutton, already referred to, says: "It is very difficult to uproot ancient tradition, especially one so ancient as the belief in the intimate association of ovulation and menstruation, but evidence is rapidly accumulating which will show that the two processes are not so intimately connected as was formerly supposed."

Leopold and Mironoff state, as their opinion, that "Ovulation usually accompanies menstruation, though not always. Menstruation depends upon the presence of the ovaries and a well-formed uterine mucosa. Ovulation usually coincides with menstruation; it rarely occurs in normal conditions between the menstrual periods."

Manton, in Jewett's *Practice of Obstetrics*, says: "Although menstruation and ovulation should not be considered as necessarily coincident processes, it is altogether probable that the conditions which influence the one have also an effect upon the other, and that, as a rule, the two functions occur simultaneously and are, to a greater or less extent, interdependent."

Williams concludes, from all the available evidence, "that the two processes usually occur about the same time, but that one not infrequently antedates the other by a few days; while in exceptional cases they may occur quite independently."

In discussing the relation between menstruation and ovulation, Edgar says that "they occur about the same time, although ovulation often follows menstruation and may occur between the menses; that the ovarian changes which precede ovulation by producing ovarian tension, reflexly excite the uterus and cause menstruation; that both processes are under some nervous control, yet either may occur independently."

It would appear, then, that the relation existing between ovulation and menstruation is not definitely determined, but that they are intimately associated cannot be questioned, for the removal of the ovaries, as a rule, is followed by a discontinuance of menstruation.

As to the relation between a particular menstrual period and the process of ovulation, Marshall says, that the decidua of a particular menstrual period is related not to the ovum discharged at that period, but to the ovum discharged at the preceding period, and which takes, probably, a week in its passage from the ovary to the uterus.

**Formation of Corpus Luteum.**—After an ovum has been discharged from a Graafian follicle certain changes take place in the latter structure which result in the formation of a *corpus luteum*. The cavity of the follicle is filled with blood from the lacerated blood-vessels of the walls of the follicle, and this undergoes coagulation, the serum being expressed and absorbed, and the clot, at first red, later becomes decolorized. Into this penetrates the tunica interna of the theca folliculi, which undergoes proliferation. In this proliferated tissue are lutein cells containing lutein, which gives the characteristic yellow color from which the corpus luteum derives its name, and fibrous connective tissue with blood-vessels whose capillaries penetrate between the lutein cells. The inner wall of the corpus luteum becomes folded in or convoluted, and the central portion of this body undergoes degeneration and is absorbed. Afterward the corpus luteum undergoes hyaloid degeneration, and the *corpus albicans* results, so called because of the white color which replaces the yellow. This is ultimately absorbed, and there remains but a small amount of connective tissue.

While a corpus luteum which occurs during menstruation exists

for but a few weeks, that which occurs in connection with pregnancy remains for a much longer period, even until after child-

FIG. 434.—Portions of ova of *Asterias glacialis*, showing changes affecting the germinal vesicle at the beginning of maturation: *a*, germinal vesicle; *b*, germinal spot, composed of nuclein and paranuclein (*c*); *d*, nuclear spindle in process of formation (Hertwig).

FIG. 435.—Formation of polar bodies in ova of *Asterias glacialis*: *pa*, polar spindle; *pb'*, first polar body; *pb''*, second polar body; *n*, nucleus returning to condition of rest (Hertwig).

A    *n*

B

FIG. 436.—A, mature ovum of echinus: *n*, female pronucleus; B, immature ovarian ovum of echinus (Hertwig).

birth. The manner of formation is, however, the same in both, only under the stimulus of pregnancy the corpus luteum which



occurs at this time becomes much larger, having a diameter of from 12 to 20 mm. The two varieties are known respectively as the *corpus luteum spurium* or of *menstruation*, and the *corpus luteum verum* or of *pregnancy*. There is, however, no essential difference between the two. It was supposed at one time that the existence of pregnancy could be determined by the presence of a corpus luteum in the ovary, but the existence of such bodies in undoubted virgins has overthrown that theory absolutely. It is said that in the mouse there is no difference as to structure or size between corpora lutea derived from follicles whose ova have been impregnated and those whose ova have not been fertilized.

**Maturation of the Ovum.**—This process takes place in all ova, and is necessary for their preparation for fertilization. In other words, an immature ovum is not susceptible of being fertilized. These changes take place while the Graafian follicle is also becoming mature, and are complete by the time the ovum is discharged from the follicle. To understand the process thoroughly one must be familiar with karyokinesis (p. 28). It may, however, here be briefly described as beginning with the migration of the germinal vesicle to the periphery (Fig. 434), the rupture of the nucleus, the formation of the spindle, etc., and the extrusion of the polar bodies (Fig. 435); and thus is formed a new nucleus, the *female pronucleus* (Fig. 436). If the ovum is unfertilized, it undergoes disintegration, probably within eight days from the time it left the ovary: but if fertilized, the female and male pronuclei, the latter being derived from a spermatozoön, fuse and form a new nucleus, the segmentation nucleus.

**Impregnation.**—In order that the ovum may be impregnated or fertilized the spermatozoa must come in contact with it in the generative passage of the female; or, more properly speaking, one spermatozoön must, for in the process of fertilization but one of these structures is involved. This is preceded by erection of the penis and ejaculation of the semen.

**Erection of the Penis.**—Any influence brought to bear upon the sexual center, which is situated in the lumbar region of the spinal cord, by which it is stimulated, results in the emission of impulses through the nervi erigentes. This influence may come from the brain in the form of mental impressions, or from stimulation of the sensory nerve-endings in the penis. The efferent impulses which reach the penis cause a relaxation of the muscular structure of the trabeculæ, thus increasing the capacity of their interspaces, and also a dilatation of the arterial vessels, so that an increased amount of blood is supplied to the organ. The veins (Fig. 437) which return the blood from the penis are relatively small, and are unable to return quickly the blood supplied by the relaxed arteries; this obstacle to the free return of the blood is augmented by the compression of the veins produced by the con-



traction of the erector penis and bulbocavernosus muscles. The result is the distention of the penis with blood, producing the rigid condition of that organ called erection. The verumontanum, which likewise contains erectile tissue, becomes at the same time rigid, and assisted by the contraction of the sphincter vesicæ, closes the passage to the bladder.

The clitoris of the female possesses an erectile structure, and during coitus undergoes a change analogous to that of erection in the male.

**Ejaculation.**—Some writers describe an ejaculatory center—that is, a special center in the spinal cord that presides over the emission of semen which constitutes ejaculation, while others deny its existence. As a result of the excitation produced by the act of copulation the testicles become very active in the formation of their secretion, and this is carried to the ampullæ of the vasa deferentia by the muscular action of the various portions of the canal which it traverses. The muscular coat of the seminal vesicles, and that of the ampullations by their contraction expel their contents, the semen, into the ejaculatory ducts, through which it is discharged into the prostatic portion of the urethra (Fig. 438). Here are added to it the secretion of the prostate, expelled by the muscular tissue of that gland, and the secretion of the glands of Cowper.

FIG. 437.—Deep dorsal vein and its tributaries: *A*, glans; *B*, *B'*, corpus cavernosum; *C*, section of pubis, made slightly below the symphysis. 1, Deep dorsal vein; 2, its origin behind the glans; 3, 3, its tributaries coming from the corpus cavernosum and corpus spongiosum; 4, dorsal vein, bifurcated and arranged in a sort of plexus, subpubic plexus; 5, plexus of Santorini; 6, 7, anastomosis of superficial dorsal vein with external pudic and obturator (Testut).

By the combined rhythmic action of the ischio- and bulbocavernosi, constrictor urethræ, external sphincter ani, and levator ani muscles, the semen is forced through the remaining part of the urethra and out of the meatus.

During copulation the glands of Bartholin, situated on each side of the commencement of the vagina and behind the hymen, and which are regarded as the analogues of Cowper's glands in the male, secrete a mucous fluid which is poured out upon the vulva.

By the vibratile movement of their tails or flagella the spermatozoa penetrate the os uteri, passing into the interior of the

uterus. According to Litzmann and others, at the time of coitus the uterine muscular tissue contracts, thus compressing the cavity of that organ; subsequently relaxation occurs and by *aspiration*, the spermatozoa are drawn into the cavity. Kristeller believes that at the time of the completion of coitus, when the orgasm occurs, the plug of mucus in the cervical canal is forced down into the vagina, and that the spermatozoa, discharged at the same moment, attach themselves to it and are drawn back with it into the

FIG. 438.—Posterior portion of urethra, seen after median incision of the anterior wall of the canal; 1, vesical neck; 2, section of prostate and urethral sphincters; 3, section of membranous urethra; 4, section of spongy urethra; 4', bulb; 5, 5', corpora cavernosa; 6, verumontanum with orifice of utricle; 7, posterior wall of prostatic urethra with its glandular openings; 8, right ejaculatory duct laid bare, with, 8', its opening; 9, Cowper's gland; 10, its excretory duct laid bare; 10', opening of this duct; 11, longitudinal fold of mucous membrane of urethra; 12, cul-de-sac of bulb; 13, collar of bulb (Testut).

uterus. Whether either of these theories is, in the main, the correct one has not been determined. That the spermatozoa can, by the vibratile motion alone of their tails or flagella, penetrate the os uteri is proved by the fact that impregnation has occurred when the woman was unconscious. The rate at which spermatozoa travel in the human female passages is one centimeter in three minutes; in the rabbit two and three-quarter hours are sufficient for them to reach the ovary. Their vitality is retained in the human passages

probably for several days and sometimes longer, after which they undergo disintegration. Dührssen found living spermatozoa in a tube which he removed from a woman whose statement, if true, would show that they had been there for fully a month.

**Ovarian and Abdominal Pregnancy.**—The portion of the female generative passages in which the spermatozoa and the ovum ordinarily meet is probably the Fallopian tube in the majority of instances. It may, however, also be the uterus.

That the place of meeting may also be the ovary is proved by the occurrence of *ovarian pregnancy*, which is one form of ectopic gestation. The proportion of ectopic to uterine gestations is variously estimated; some writers placing it at 1 in 500, and others at 1 in 10,000. Of ectopic pregnancies, Edgar thinks 4.8 per cent. are ovarian. Williams regards only 5 reported cases of primary ovarian pregnancy as having been conclusively demonstrated, 30 cases as highly probable, and 25 as fairly probable. Four cases are reported by such competent authorities as Leopold, Patenko, and Martin. It may be interesting in this connection to say that in Patenko's case the right ovary, which was about the size of a hen's egg, contained a cyst within which was a yellow body consisting of cylindrical and flat bones, which upon examination were found to be fetal, and not such as are found in dermoid cysts. In the wall around the cyst were found corpora lutea and Graafian follicles, showing that the tissue was true ovarian tissue. Martin reports 2 cases which he regards as undoubtedly primary ovarian pregnancies; 1 of these is shown in Fig. 439. He believes that in cases of ovarian pregnancy the spermatozoön finds its way through the fimbriated extremity of the Fallopian tube into one of the small, recently ruptured, cysts so often seen on the surface of the ovary, and there fertilizes the contained ovum.

As to the occurrence of *primary abdominal or peritoneal pregnancy*, there is great difference of opinion. Some writers, while recognizing its possibility, doubt that it has ever actually occurred. When the impregnated ovum is implanted upon the fimbria ovarica the subsequent growth would make it appear to be a peritoneal or abdominal pregnancy. Schlechtendahl's case would, however, appear to have been an instance of primary abdominal pregnancy. In this case a fetus 15 cm. long was found attached to the abdominal wall, near the spleen, of a woman who had died from hemorrhage. Should this form of pregnancy occur, it would be explained by the meeting of the spermatozoa and the ovum at the time of the escape of the latter from the Graafian follicle, which, instead of entering the Fallopian tube, falls into the peritoneal cavity, where it would subsequently become developed.

Webster, in his *Ectopic Pregnancy*, in which he considers the subject most exhaustively, states it as "extremely probable that

no gestation can begin its development, except in some part of the genital tract derived from the Müllerian ducts which form the uterus and tubes." This, of course, rules out both abdominal and ovarian pregnancy. Of the latter, Webster says: "Supposed cases of ovarian pregnancy require to be studied carefully, and in every instance must be distinguished from the following conditions, which may be mistaken for it, viz., pregnancy in the outer

FIG. 439.—Prof. August Martin's case of ovarian pregnancy. The intact tube is seen lying above the ovarian sac containing the fetal envelopes.

end of the tube which has become intimately connected with the ovary; pregnancy in an accessory tube-end which has become attached to it; pregnancy in the ovarian fimbria, which may be hollow sometimes, representing the extreme outer end of the tube; pregnancy in the tube which has extended into the ovarian sac of peritoneum, which occasionally occurs in women."

The terms "extra-uterine pregnancy" and "ectopic pregnancy" are ordinarily used synonymously, but there is really a distinction.

The term "ectopic" implies that the gestation is outside the *uterine cavity*. A gestation may occur in that part of the Fallopian tube which is situated in the uterine wall. Such an one, described under the name "*interstitial*," would not be "extra-uterine," for it is within the uterus. It would, however, be "ectopic." If the view of Webster is correct, all ectopic gestations must be of tubal origin. He divides them into five subdivisions: 1. *Ampullar*, in which the gestation begins in the ampulla or middle portion of the tube, and he regards this as by far the most common. 2. *Interstitial*, in which the gestation develops in that

portion of the tube situated in the wall of the uterus. 3. *Infundibular*, in which the gestation develops in the outer end of the tubulumen or among the fimbriæ. 4. *Anomalous Varieties*.—Among these Webster places those that develop in accessory fimbriated extremities or in tubal diverticula, and also those that develop in detached portions of Müllerian tissue—i. e., those attached to or embedded in the ovary. In this class, he thinks, are some of the recently described cases of ovarian pregnancy. 5. *Cornual pregnancy*, in which the ovum develops in the undeveloped horn of a bicornate uterus.

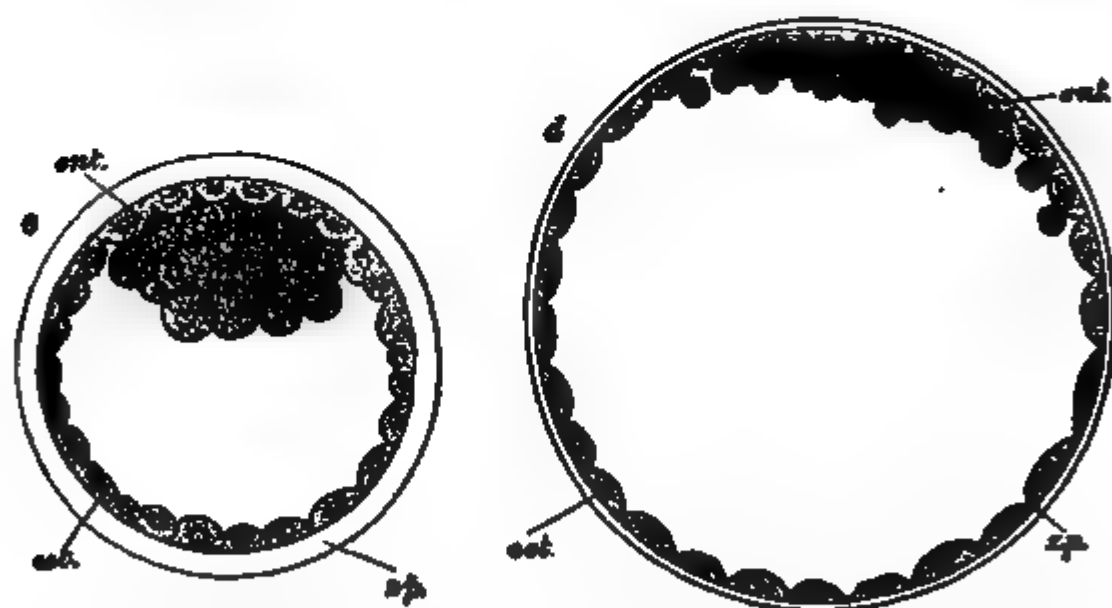


FIG. 440.—Sections of the ovum of a rabbit, showing the formation of the blastodermic vesicle: a, b, c, d, are ova in successive stages of development; sp, zona pellucida; ect, ectomeres, or outer cells; ent, entomeres, or inner cells (E. Van Beneden).

**Method of Fertilization.**—In the vitelline membrane of the ova of some animals there is a minute opening, the *micropyle*, by which a spermatozoön gains access to the interior. Such an opening does not exist in the human ovum. Some histologists have described the vitelline membrane as possessing a porous structure, and it has been suggested that through one of these

pores a spermatozoön might pass. It is by no means established that such pores exist. However, in some way the spermatozoön passes through the membrane into the protoplasm; here its tail disappears and the head assumes a spherical form, and to it the name of "male pronucleus" is given. The male and female pronuclei then unite to produce the *fecundation nucleus*. After this occurs the ovum consists of a mass of protoplasm with a nucleus, and is spoken of as the "segmentation sphere," because it undergoes segmentation.

**Segmentation.**—This consists in the production of two segments by the same process of indirect division which takes place in the germinal vesicle; these again divide, forming four, and, the same process continuing, the entire ovum is broken up into a mass of spherical cells which, from the resemblance to a mulberry, is named *morula*. These cells separate into two layers, with fluid between them, except at one place where the layers are in contact. The blastodermic vesicle is now formed. It is probable that development has reached this stage at about the tenth day, by which time the ovum has entered the uterus. The albuminous secretion of the Fallopian tube serves as pabulum or food to the cells in this process.

**Formation of Embryo.**—The next change which takes place is the formation of three layers from the two just described. They are termed the *epiblast*, the *mesoblast*, and the *hypoblast*; together they form the *blastoderm*. The epiblast is most external, in contact with the vitelline membrane, which takes no part in the changes thus far described.

It would, perhaps, be too much to say that the embryo is now formed, yet the subsequent changes are but the modification and differentiation of the cells which compose these three layers. The epiblast forms the brain and spinal cord, portions of the organs of special sense, and the epidermis, and also takes part in the formation of the chorion and amnion. The mesoblast forms the vascular, osseous, and muscular systems, and the endothelium which lines the serous cavities. The hypoblast forms the lungs, the epithelium of the alimentary canal and of the glands which are offshoots from this canal. The membrane which lines the allantois and the yolk-sac is also formed from the hypoblast.

The segmentation just described is such as takes place in the human ovum and that of other mammalia. It is a process in which the entire mass of protoplasm undergoes division: such ova are said to be *holoblastic*. In the ova of birds and of reptiles only a portion undergoes this segmentation, the rest serving as food. Such ova are *meroblastic*. As an illustration of the latter may be mentioned the fowl's egg, in which the processes of development have been most thoroughly studied. In this egg only a minute portion, the *cicatrix*, becomes converted into

the chick, while the great body of material nourishes the growing embryo until it leaves the shell and is able to gain its own livelihood. As such an embryo is never attached to the parent, it must have within itself, supplemented by what it receives from the air, all the material necessary for its development and maintenance until freed from its enclosing shell, hence the large size of the ovum ; while in the mammal this supply is not necessary, for the attachment to the maternal structures is made at an early period of its history, and from the parent all necessary sustenance is obtained.

Inasmuch as development has been so much more thoroughly studied in the hen's egg than in any other, and inasmuch as the processes are in many respects probably the same as in the human ovum, the development of the chick will be described, referring to the principal points of difference as they are reached in the description, giving, however, only a general view of the subject, which is much too extensive and complicated to discuss in any other manner in this connection, and referring our readers for fuller details to monographs on embryology.

**Development of Chick.**—If the shell of a hen's egg is broken during the first day of its incubation and the blastoderm is examined, it will be seen that there is a clear central portion, the area pellucida, and a portion outside of this, the area opaca, which is much less clear. The embryo forms in the area pellucida, and the membranes and structures which are to nourish it form in the area opaca. On the second day, the area opaca having meanwhile extended, within it are formed red blood-corpuscles and vessels, and during the same time in the area pellucida the heart is formed. These structures arise, as has been stated, from the cells of the mesoblast.

At one extremity of the area pellucida a fold forms in the blastoderm, and, as this is the anterior end, it is called the *cephalic fold*. A similar fold, the *tail fold*, forms at the other extremity of the area pellucida. In the same manner *lateral folds* form on the sides. All these folds, which include the three layers of the blastoderm, approach one another below, and by so doing form a canal, the embryonal sac. This sac is bounded above by the blastoderm, anteriorly by the cephalic fold, posteriorly by the tail fold, and laterally by the lateral folds, while below it is in communication with the vitellus. This embryonal sac subsequently becomes divided into two, one division forming the alimentary tract, and the other the body-walls, the umbilicus being the point at which the folds all unite. These folds just described are to be carefully distinguished from the membranes, the amnion, the chorion, etc. The folds, as stated, involve the epiblast, the mesoblast, and the hypoblast, while in the formation of the membranes the various layers play different parts.

**Membranes of the Embryo.—Amnion.**—The mesoblast about the embryo splits into two laminæ, the parietal and the visceral. The parietal (external) joins with the epiblast to form the *somatopleure*, from which the amnion and the body-walls are developed, while the visceral lamina unites with the hypoblast to

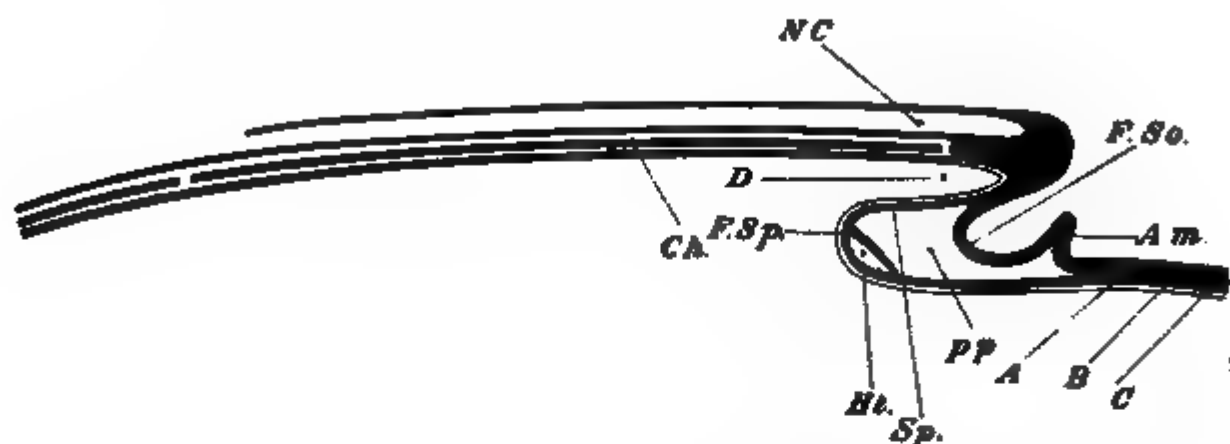


FIG. 441.—Diagrammatic longitudinal section through the axis of an embryo chick: *N. C.*, neural canal; *CA*, notochord; *D*, foregut; *F. So.*, somatopleure; *F. Sp.*, splanchnopleure; *Sp.*, splanchnopleure forming the lower wall of the foregut; *Ht.*, heart; *pp*, pleuroperitoneal cavity; *Am.*, amniotic fold; *A*, epiblast; *B*, mesoblast; *C*, hypoblast (Foster and Balfour).

form the *splanchnopleure*. From this structure are developed the walls of the *allantois*, the yolk-sac, and the alimentary canal. Between the somatopleure and the splanchnopleure is the pleuroperitoneal cavity, which later is divided by partitions into pericardial, pleural, and peritoneal cavities. From the somatopleure folds form which rise above the embryo on all sides, meeting over

FIG. 442.—Diagrammatic longitudinal section of a chick on the fourth day: *ep.*, epiblast; *hy.*, hypoblast; *sm.*, somatopleure; *vm.*, splanchnopleure; *af*, *pf*, folds of the amnion; *pp*, pleuroperitoneal cavity; *am.*, cavity of the amnion; *at.*, allantois; *a.*, position of the future anus; *h.*, heart; *i.*, intestine; *vi.*, vitelline duct; *ys.*, yolk; *s.*, foregut; *m.*, position of the mouth; *me.*, the mesentery (Allen Thomson).

its back and fusing together. These are the amniotic folds. As each fold is double, when they unite two membranes result: the inner, next the embryo, is the amnion, and the outer, toward the vitelline membrane, is the false amnion (Fig. 442). The latter and the vitelline membrane fuse together, forming the chorion.



The true amnion has epiblast for its inner, and mesoblast for its outer, layer, and the space between it and the embryo is the amniotic cavity, in which the liquor amnii accumulates.

**Yolk-sac.**—The yolk-sac is a very important structure in the fowl and in birds generally, as it is upon the yolk that the nutrition of the embryo depends; but in mammals it is of little importance, as the nutritive material in the vitellus is insignificant in amount.

**Allantois.**—The allantois is a projection of the splanchnopleure into the pleuroperitoneal cavity. It subsequently communicates with the posterior portion of the intestinal canal, and its lining is hypoblast. This structure projects more and more into the pleuroperitoneal cavity, following up the folds that have been described as forming the true and the false amnion. The allantois at last comes in contact with the chorion, which, it will be remembered, was formed by the fusion of the false amnion with the vitelline membrane, and into the villi of that structure it sends processes. It is especially developed in that part corresponding to the attachment of the ovum to the uterine wall. The allantois has two layers, a mesoblastic and a hypoblastic. In the former are blood-vessels which come from the vascular system of the embryo, the connecting vessels becoming the umbilical arteries. At a later stage of development the character of the allantois disappears, except in that portion which is to be included within the body of the fetus, and which becomes the urinary bladder, and in that portion between the bladder and the umbilicus, which becomes the urachus.

**Chorion.**—This membrane, as already stated, is formed by the union of the vitelline membrane and the false amnion. When first formed, it is smooth, but becomes shaggy by the growth from it of processes called *villi*. These villi are at first scattered over the whole exterior of the ovum, but later they are found only at the point of attachment of the ovum to the uterus, where the placenta is to be formed. In these villi are blood-vessels from the fetal vascular system.

**Placenta.**—When the impregnated ovum reaches the cavity of the uterus the mucous membrane of that organ is prepared to receive it, and it finds a lodgment there. Under the stimulus of impregnation the whole mucous membrane becomes thickened, and at the termination of uterogestation the entire mucous membrane of the body is cast off; it is called the *decidua vera*. Especially marked is this thickening at the point of attachment of the ovum, and to this part the name *decidua serotina* is applied (Fig. 443). As a result of this stimulus the mucous membrane increases around the ovum, finally completely enclosing it. This new formation is the *decidua reflexa*.

The villi of the chorion find their way into the depressions of

the decidua serotina, and their walls become atrophied, being finally represented only by epithelial cells covering the capillary blood-vessels which have come from the allantois. The blood-vessels in the decidua serotina become converted into blood-spaces, sinuses, to which the uterine arteries carry blood, and from which the uterine veins carry the blood away. It will be seen, therefore, that the fetal blood-vessels are surrounded by the maternal blood in the uterine sinuses, the two fluids being separated only by the thin wall of the fetal capillaries, through which the interchanges of oxygen and carbon dioxide take place, and also the passage of the nutritious material to supply the growing fetus, and in the reverse direction pass the effete products to be eliminated. The structure which performs all these important offices is the *placenta*, made up of both maternal and fetal tissues. It seems hardly necessary to say that the blood of the mother and that of the child never come in contact, but are always separated by the walls of the fetal capillaries.

At birth the placenta is cast off, and by the contraction of the uterine muscular tissue the mouths of the maternal blood-vessels are closed, and thus hemorrhage is prevented. The blood which escapes during a normal labor is that which was in the sinuses. The functions of the placenta are thus seen to be threefold—nutritive, respiratory, and excretory.

**Circulation in the Embryo.—Vitelline Circulation.**—During the earliest part of human fetal life the contents of the ovum supply the growing embryo with nutrition. This is done by means of vessels which compose the vitelline circulation, but, important as this circulation is in the fowl's egg, it is of very brief duration in the human subject, for the supply of nutritious material is soon exhausted, probably at the sixth week.

**Placental or Fetal Circulation (Fig. 444).**—By the sixth week the placenta is formed and the connection has been made by which the embryo receives its nourishment from the maternal blood.

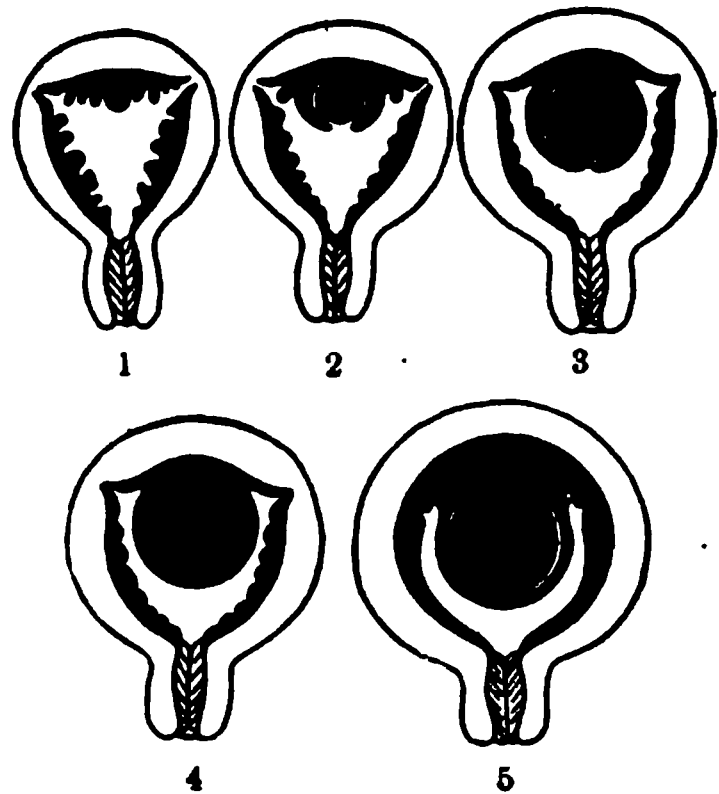


FIG. 443.—Series of diagrams representing the relationship of the decidua to the ovum at different periods. The decidua are colored black, and the ovum is shaded transversely. In 4 and 5 the vascular processes of the chorion are figured. 1, Ovum entering the congested mucous membrane of the fundus—decidua serotina; 2, decidua reflexa growing around the ovum; 3, completion of the decidua around the ovum; 4, general growth of villi of the chorion; 5, special growth of villi at placental attachment, and atrophy of the rest (copied from Dalton).



discharges its blood into the right auricle of the heart, where, guided by the Eustachian valve, it is directed into the left auricle through the foramen ovale. From this cavity it passes into the left ventricle, thence into the aorta, which distributes it to the head and upper extremities. It will be seen from this description that to these three portions of the body the blood from the placenta is distributed. This blood is not very pure, for it is deteriorated by admixture with the impure blood returning from the lower extremities, with which it mingles in the ascending vena cava; but it is the purest and most nutritious blood the fetus receives, and this accounts for the greater development of the upper portion of the body as compared with the lower, which is so striking a feature in the newborn babe.

The blood returns from the head and upper extremities through the descending vena cava to the right auricle, and thence passes into the right ventricle. There is probably always a slight mixing of the currents in the right auricle, that returning from the placenta and that from the descending vena cava, but at first this is very slight; later, it is doubtless greater. From the right ventricle the blood passes into the pulmonary artery, a very small portion going through the capillaries of the lungs, the larger part passing through the ductus arteriosus into the aorta, passing down this vessel to the common and internal iliacs, from which latter are given off the hypogastric or umbilical arteries by which the blood is conveyed to the placenta.

By comparing this description with that of the circulation in the adult the points of difference will be seen. It may be well to note here that there are six principal points of difference between the fetal and the adult circulatory apparatus, besides less important ones of size and shape. These points of difference are the presence in the fetal heart of the Eustachian valve and the foramen ovale, in the venous system of the umbilical vein and the ductus venosus, and in the arterial system of the umbilical arteries and the ductus arteriosus.

**Changes in the Circulation at Birth.**—During intra-uterine life the respiratory center in the medulla is supplied with blood containing sufficient oxygen to prevent any inspiratory impulse, and there is therefore during this period no attempt at respiration on the part of the fetus. As soon, however, as the connection between the parent and the child is severed, whether by separation of the placenta or by tying of the umbilical cord, the respiratory center, being no longer supplied with oxygen, sends out impulses to the respiratory muscles, and respiration begins. This may be hastened or assisted by slapping the skin or dashing water upon it, but under ordinary circumstances these measures are not called for. The fact that respiration will take place while the fetus is still enclosed in its membranes, without the reflex in-

fluence of exposure to the air, shows that this is not the essential, but only a contributing, cause. It is the stoppage of the placental circulation which starts the respiratory movements.

Although during fetal life some blood flows through the pulmonary capillaries, still the amount is small, and, there being no air in the pulmonary alveoli, the lungs will sink if placed in water. The first respiratory movement causes an enlargement of the thoracic cavity and a consequent distention of the lungs, the air passing into the alveoli, and the blood, which is at the time in the pulmonary capillaries, becomes oxygenated and returns to the left auricle as arterial blood. The expansion of the thorax reduces the resistance to the flow of the blood through the pulmonary circulation, and as a result a large amount of blood goes to the lungs; this means a lessened amount through the ductus arteriosus, and, following the law that a diminution of function is followed by atrophy, this vessel begins to diminish in size, and becomes closed between the fourth and tenth days, and in later life is to be found as a fibrous cord between the left pulmonary artery and the aorta.

With the termination of the placental circulation the flow through the ductus venosus ceases, and within a few days this vessel closes, and remains only as a fibrous cord in the fissure of the same name in the liver: that portion of the umbilical vein which is within the body of the child becomes the round ligament of the liver. The blood flowing into the right auricle from the inferior vena cava finds it easier to pass into the right ventricle than into the left auricle, which is now filled with blood from the lungs, and hence takes this course, while the blood cannot flow into the right auricle through the foramen ovale by reason of the valve which has been forming in the left auricle during the latter part of intra-uterine life to close this opening. The opening is not permanently closed for a considerable time after birth, in some cases a year, and sometimes not at all. As a result of these various changes the fetal circulation becomes converted into that of the adult.

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